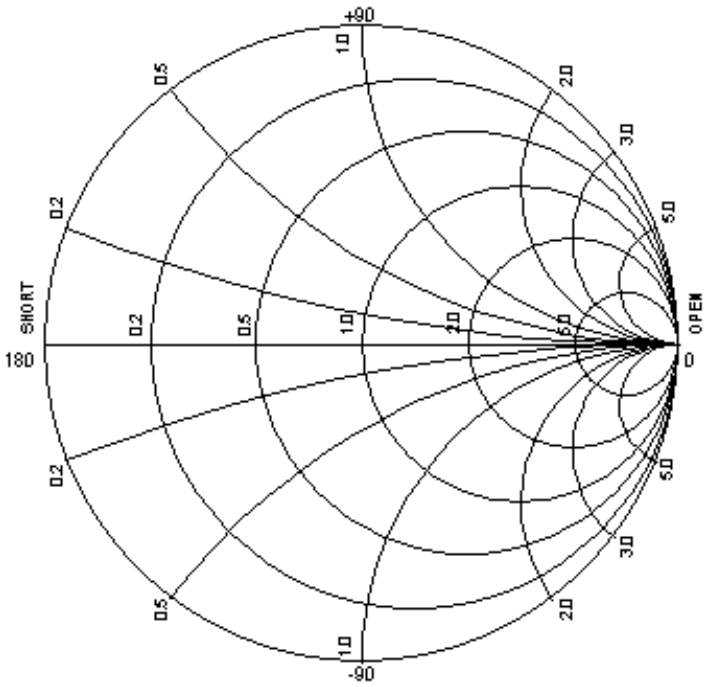
NanoVNA V2+/+4
PC Interface
INSTALLATION and USERS MANUAL



December 4, 2020 – January 22, 2021

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1. Documentation Update Log

Page Nos.	Amendment	Rev	Date
All	Draft	0.04	December 5, 2020
All	Add crystal measurements and segmented sweeps	0.05	December 6, 2020
All	Add TDR, Touchstone and filter sections	0.06	December 7, 2020
All	Add calibration interpolation	0.07	December 10, 2020
All	Add offset loss to calibration Update points when loading previous calibration Change all frequencies to Hz and use SI units Use standard units for RLC Normalize all memories Record normalized data if selected Use common terms, Start, Stop, Port 1 & 2 Add details regarding the transfer relay	0.08	December 11, 2020- January 9, 2021
All	Corrections from review	0.09	January 22, 2022

2. Trademarks

- Intel is a registered trademark of Intel Corporation or its subsidiaries in the United States and other countries.

- Microsoft and Windows are registered trademarks of Microsoft Corporation in the United States and other countries.

- LabVIEW, National Instruments, NI, ni.com, the National Instruments corporate logo, and the Eagle logo are trademarks of National Instruments Corporation.

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3. Scope

This software is loosely based on a program I had written for my HP8754A, which still requires a copy of Windows XP to run. After receiving the original NanoVNA, the software was rewritten to support it along with Windows 10. It was then used as a basis for my other vintage VNAs. The real benefit is that the software has the same look and feel for all of my analyzers and it allows me to automate various experiments.

Upon receiving the V2+ and being unsuccessful with the standard software supplied with it, it made sense to support it as well. I have no need to support multiple analyzers with one software package. However, there are features that the software supports that the V2+ is lacking. Namely, any narrow band work.

This software supports measuring and sorting your collection of crystals to design your next filter. However the V2+ just isn't up to the task. I had hoped that the new V2+ would out perform my original NanoVNA in every way but it's not the case.

There are a few undocumented differences between the V2+ and V2+4 that were discovered during the development of this software. The primary difference has been that the V2+ appears to lockup during long data collections and requires being power cycled to recover. This hasn't been seen with the V2+4. In this document, I will refer to both the NanoVNA Version 2 Plus and Version 2 Plus 4 as the V2+. As far as the software is concerned, the products are the same.

The author is not an amateur radio or citizens band hobbyist. Because the software was written for my own personal use, there are many features that may be lacking or have not been completed. This is most likely due to my lack of having a use for them. Some parts of the software may be doing something totally different than what a typical user may expect. I change the software often depending on the tests I am trying to run.

This software can be viewed as an engineering tool at best. Its primary use was to extend the author's understanding of V2+. It was never intended to be used as a general tool for radio hobbyist to tune their antennas. The software is fairly buggy and not very robust. Even under normal conditions, expect to run into several problems if attempting to use this software. It's a very poor choice for the beginner.

This manual assumes the reader is PC literate and has some basic understanding of how a VNA works. It is not a learner's guide on using a VNA and offers no assistance into solving basic computer related problems.

The software is continually being developed. You may find some screen shots and features change throughout this document as a result.

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4. Basic Architecture

The software was written in LabView, which is a graphical programming language. LabView was developed for automating tests and is well suited for this type of application. Labview allows creating highly parallel programs which we will take advantage of with this software.

At the top level, the software has three threads. The lowest thread does nothing more than request data from the V2+, reads data from the communications port, performs a checksum and places the valid data into a queue. The queue is fairly deep and can handle any system delays that could possibility occur with the next thread.

The second thread waits for a valid entry in the queue. It pulls the entry and checks its index. The index is nothing more than the current sample's position in the sweep. If we are sweeping from 1.0 to 1MHz, the first sample has an index of 0. The second is 1 and so on. This thread then builds up an entire data set for one sweep. Once the full data set is available, it then applies any coefficients to the data and filters it. The data is then passed onto the main thread.

The third thread is the main program which is responsible for plotting the data to the screen, recording data to disk and making measurements. It also handles any user requests, for example, changing the start frequency.

Many of the subroutines are also processed in parallel. If you view the software in the task manager, there may be several threads running at a time.

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5. Applicable Documents

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed.

NUMBER	TITLE/AUTHOR
1EZ43_0E	T-Check Accuracy Test for Vector Network Analyzers using a Tee-junction / Rohde&Schwarz
	Measurement of Electronic Component Impedance Using A Vector Network Analyzer / Copper Mountain Technologies
ED-11192A	Terminiation SMA ANNE-50+ Mini-Circuits

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6. Definition of Terms and Acronyms

Acronym	Definition
BW	Band Width
Cal	Calibration
CW	Continuous Wave
Dec	Decade
FIFO	First In First Out
FWHH	Full Width Half Height
HPAK	Hewlett Packard Agilent Keysight
IntpCal	Interpolate Calibration
PCB	Printed Circuit Board
Ref	Reference
SOLT	Short Open Load Thru (through)
Xfer	Transfer
Xtal	Crystal

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7. Feature Summery

The following features are supported

- Supports Agilent's standard coefficients
- Performs interpolation of calibration
- Generic support for add-on transfer relays
- Supports external up/down conversion
- Supports linear stage for TDR experiments
- Supports both the NanoVNA V2+ and V2+4
- Requires LabView 2011 runtime engine
- Tested with Windows 10

8. Installation

Depending on what features you want to use and what peripherals are attached to your NanoVNA V2+, you may need to install additional drivers. The software will include an installer which contains the runtime engine only. No drivers will be included.

8.1 Before you begin

You will want to have all the drivers installed and make sure your PC is seeing the device before getting started. The software was tested using both the recommended Cypress as well as MicroSoft's included drivers. No differences in their performance was noted.

USB Serial Port (COM5)

Driver Provider:	Cypress
Driver Date:	10/13/2015
Driver Version:	3.13.0.59
Digital Signer:	Microsoft Windows Hardware Compatibility Publisher

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USB Serial Device (COM4)

Driver Provider:	Microsoft
Driver Date:	6/21/2006
Driver Version:	10.0.18362.1
Digital Signer:	Microsoft Windows

9. Button Quick Reference

The software contains quick tips. Hover the mouse over the button to see a description.

10. Getting Started

For some of this section, we will be using the included cables, modified calibration standards and a low cost set of attenuators available from various sources. The one we will be using is shown below.

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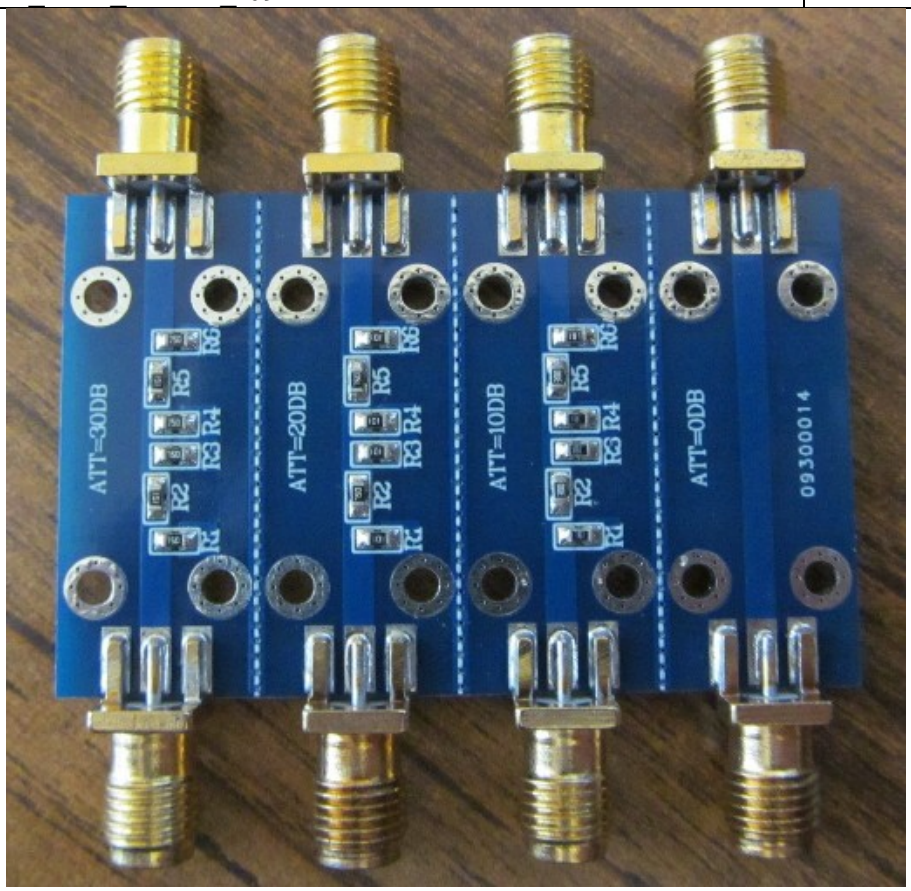

Features:
1.Special usage: This is a DC 4.0GHz RF Radio Frequency Fixed Attenuator.
2.The board layout is reasonable: beautiful, little current sound.
3.Uses the high quality material: stable and reliable performance.
4.Portable design: easy to install.
5.Good quality:durable to use.

Descriptions:
1.The is a DC 4.0GHz RF Radio Frequency Fixed Attenuator Maximum power 23dBm SMA Double Female Head 0dB 10dB 20dB 30dB.
2.Compact design, easy to install.

Specifications:
Color:Green
Frequency range: DC-4.0GHz
Maximum power: 23dBm (200mW)
Standing wave ratio: 1.20
System impedance: 50
RF : SMA double female head (Outer screw inner hole)
Attenuation:

Direct: 0dB (reference)
Level 1: 10 0.8 dB
Level 2: 20 1.1 dB
Level 3: 30 1.5dB

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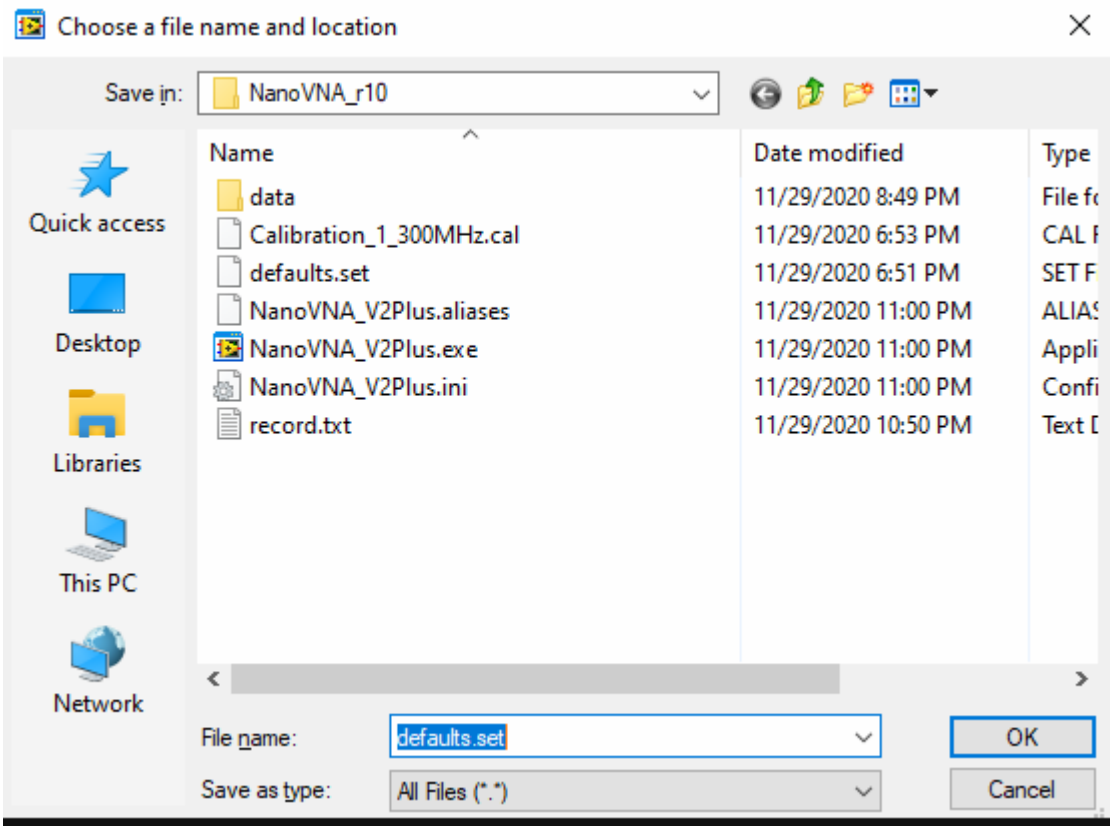
10.1 Software Defaults

When starting the software, it will prompt you for a file that contains the default settings.



This file is not ASCII readable. It contains information about serial port settings, units, calibration standards and what peripherals are available. If you don't have a default setup, just select cancel and the software will load with its default values.

Once the software has loaded you will be presented with the main menu. At this time, the software has not made any attempt to connect to the V2+ or any of the peripherals. If you do not yet have a properly configured, default file, you will need to create one before attempting to do anything else with the software.

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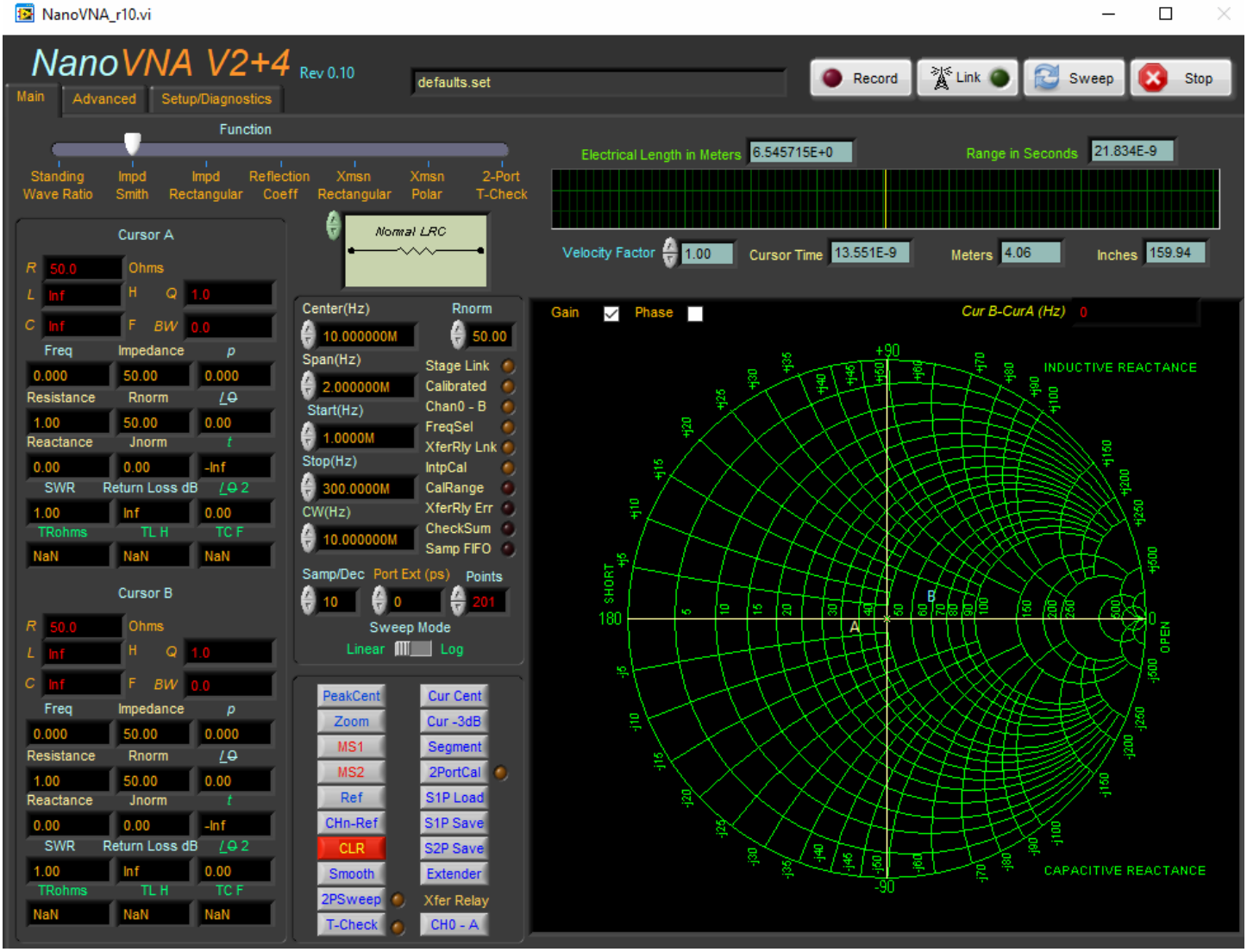

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10.2 Selecting the Communication Port

You will now need to setup the software. Start by selecting the Setup/Diagnostics tab.

In the upper right, select the communications port for the V2+. The BAUD rate for this device will have no effect on the transaction rates and can be ignored.

10.3 Selecting Calibration Standards

A quick word on using calibration standards. If you are familiar with HP, Agilent and Keysight (HPAK) analyzers, you may find the format familiar. This is by design. At this time the Loss and Delay coefficients for

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both the Load and Thru are ignored. You may also notice the software supports a port extension setting on the main page.

For the calibration standards, I suggest leaving the custom ideal standard selected. If you have characterized your standards against a known set, you may enter the data into the calibration standards tables.
You may create a new standard or modify an existing set. You may add as many standards as you like. You may scroll through the available standards with the up/down arrows. The set currently displayed is the one being used. You may also copy/paste/insert and delete standards. This entire database of standards is stored into the default file. Again, you may have more than one default file as well.

The V2+ was designed to work above 3GHz but it seems to have a fair amount of leakage (or cross coupling) between ports 1&2. Using the leakage terms can introduce noise into the reading and is normally ignored. However, it seems that without accounting for these terms with the V2+, the errors above 3GHz make the unit useless. You may manually enable these by selecting Leakage Terms. This setting is stored into the default file.

Once you have everything the way you like it, just select the SaveSetup and the software will prompt you for a file name. Use the default and select OK.

Keep in mind that you can change all of the settings at any time. You do not have to save them in order for them to take effect.

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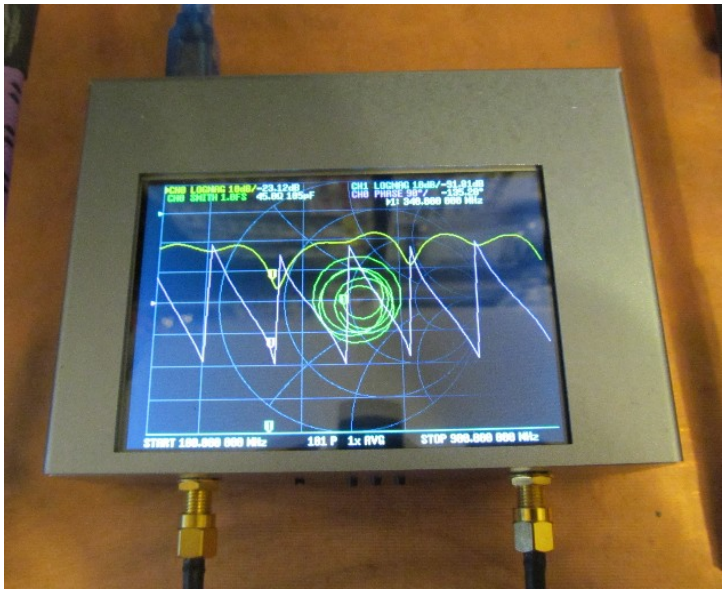
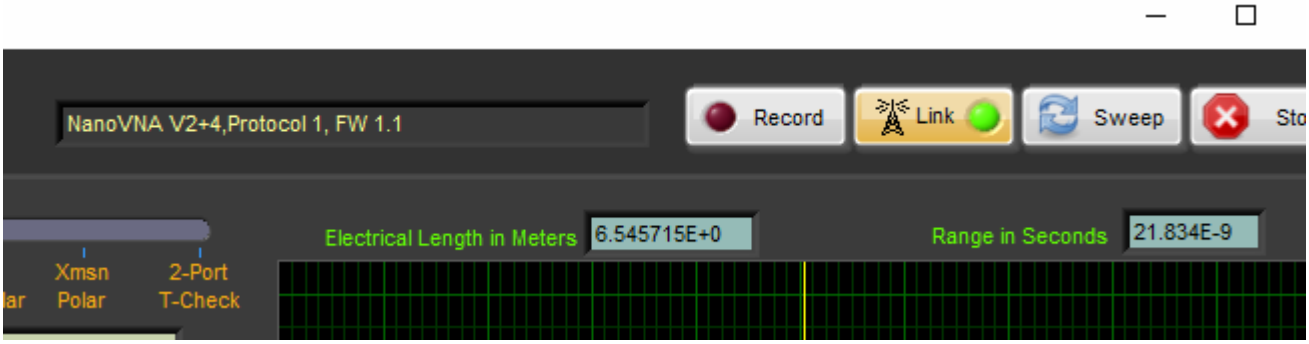
10.4 Linking to the Device

When the V2+ is powered on, the LCD will show the previous configuration.



With the proper serial ports selected and known working, return to the main page and select Link. If the software locates the V2+, the link LED will turn green and information about the VNA will be displayed in the status bar (top center of screen).



The Nano will display USB MODE. There is absolutely no use for the display when using the V2+ with the PC. As a matter of fact, the author has performed tests with the LCD completely removed, using only the main PCB.

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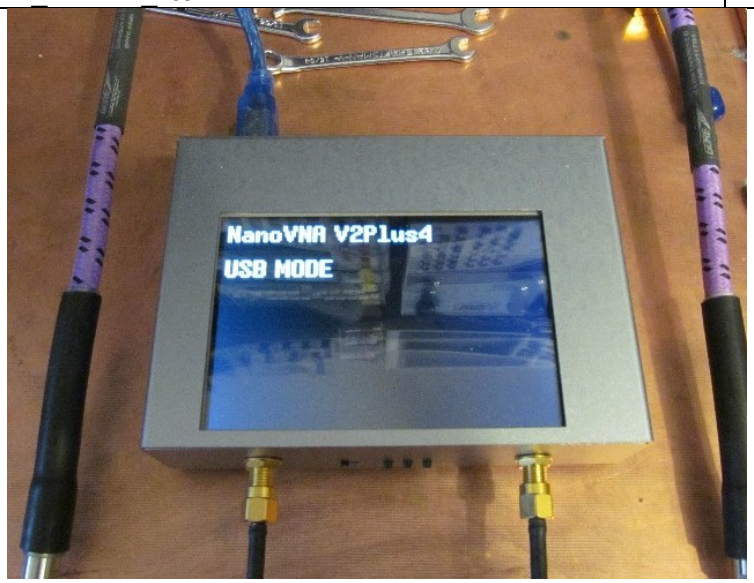
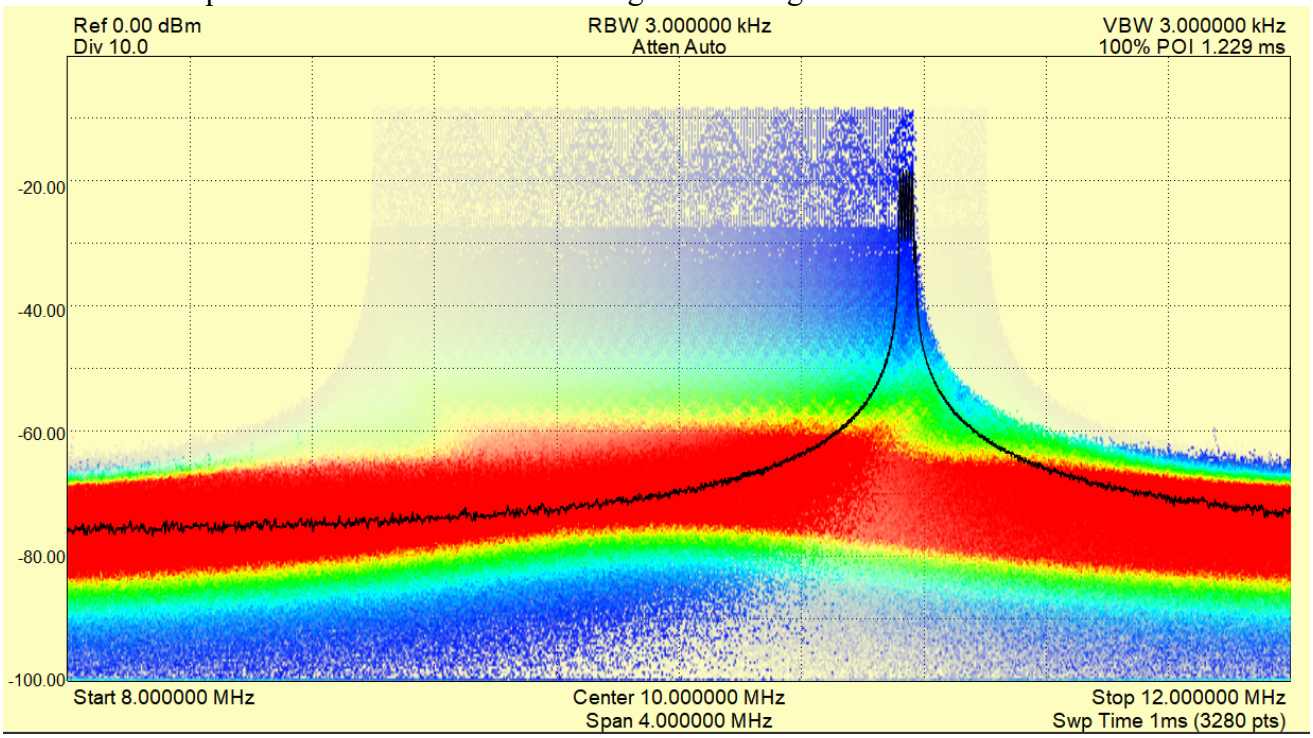


10.5 Displaying Data

The software will default to a center frequency of 10MHz with a 2MHz span and 201 data points. The V2+ was programmed with these defaults when the connection was made. The V2+ is actually sweeping at this time. Select the Sweep button and the software will begin collecting data from the V2+.



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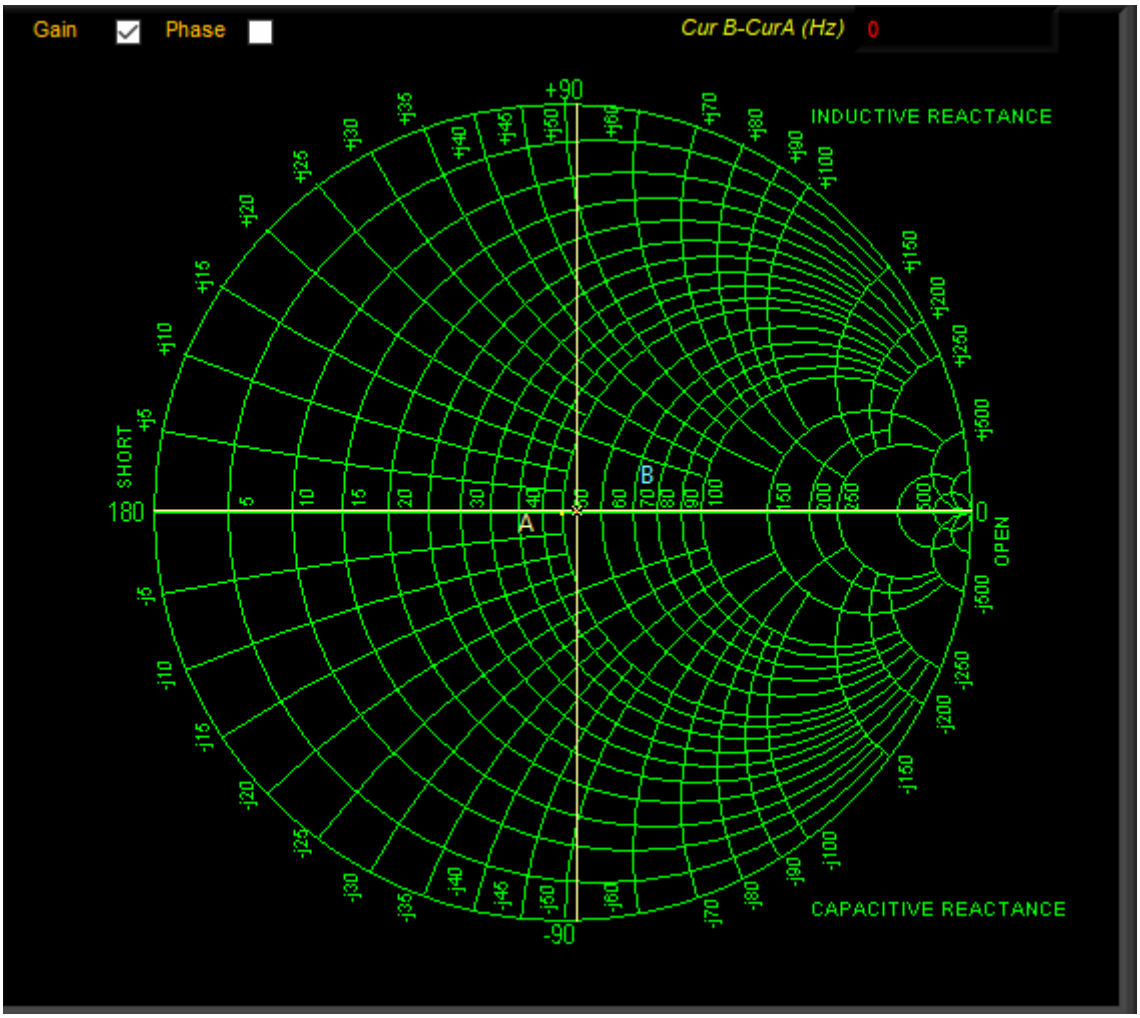
10.6 Normalization Example

In the following graph, a 10dB attenuator had been attached between Port 1&2. We can see that S11 is showing very close to 50ohm without performing any calibration.



Let's change the Stop frequency to 1GHz. The software understands SI units as well as exponents. All of the following are interpreted as 1GHz:

1000000000
1000000k
1000M
1G
1e9
1000e6

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… and so on. Units are displayed in SI format. We now see that our attenuator no longer appears to behave as a 50 ohm load.

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Select the transmission function Xmsn Rectangular. The attenuator is within 1.5dB again, keeping in mind we have no yet performed any calibration. When the V2+ is being controlled by USB, all of the data is raw. No internal coefficients are being applied.

We can get a better idea of what this attenuator looks like without performing a full calibration or selecting any standards. We do this by normalizing the data.

The first thing to do is replace the attenuator with a thru.

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This would normally be 0dB but as shown, the measurement is roughly 1.3 dB higher than expected.

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Select the Ref button which will temporarily store the swept data as a reference. Next select the CHn-Ref. This will cause the software to use this reference to normalize all further readings to zero. With the thru still inserted, the software now displays very close to 0dB +/-0.02dB.

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Reinserting the 10dB attenuator, we can now see the software displays within 0.5dB over the entire swept range.

As was mentioned earlier, the V2+ exhibits a fair amount of cross talk and normalization may not always yield good results. To demonstrate this, start by changing the Stop frequency to 4GHz. Next change the start frequency to 2.5GHz. Next, deselect the Phase checkbox in the upper left corner of the graph. Now deselect the CHn-Ref to turn off the normalization and reinstall the thru.

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As we can see rather than 0dB, the V2+ is displaying from -2 to -5dB. The waveform should be very stable.

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As before, go ahead and select the Ref followed by CHn-Ref to once again normalize the data. As shown, the data is now within +/-0.1dB over the entire 1.5GHz range.

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Now lets install the 30dB attenuator section. You may notice that the V2+ displays something other than 30dB.

Just how much of that error is from the low cost attenuator? Let's consider the cost of this set was in the order of $5. As a comparison, let's install an 18GHz, 30dB attenuator from Midwest Microwave.

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The data for this part looks much better. However, once we get above 3GHz the error greatly increases.

To further demonstrate these errors, the thru was reinstalled and the VNA was programmed to sweep from 2.5 to 4.4GHz. The number of data points was changed from 201 to 401. A new reference was then stored. The thru was then replaced with an 18GHz, 30dB attenuator from Midwest Microwave.

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Is the attenuator really this poor, or is it the V2+? Midwest isn't known for making poor products and we would expect better performance from the V2+. So what's going on? As mentioned, normalization may not always work very well.

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10.7 The V2+ SOLT Standards

It's time to try and calibrate the V2+. I purchased both the V2+ and the V2+4 with cables and standards. There are a few problems with these. The short's center conductor is locked and will turn as the nut is tightened. The thru standard doesn't have a flat. There is no way to hold it securely with your ignition wrench while you torque it.

The bigger problem is the return loss of the load is not very good. The following compares the load supplied with my original Nano against the two included with my V2+ VNAs, along with two Mini-Circuits ANNE-50+ terminators. Also shown as a reference, the Keysight 85033 standard load. (No standards were harmed during these measurements!!)

We can see the loads supplied with my two V2+ VNAs have very similar performance and offer a much improved return loss over the standard that was supplied with my original Nano. However when we compare these with the Mini-Circuits ANNE's that were hand selected, they are not as good.

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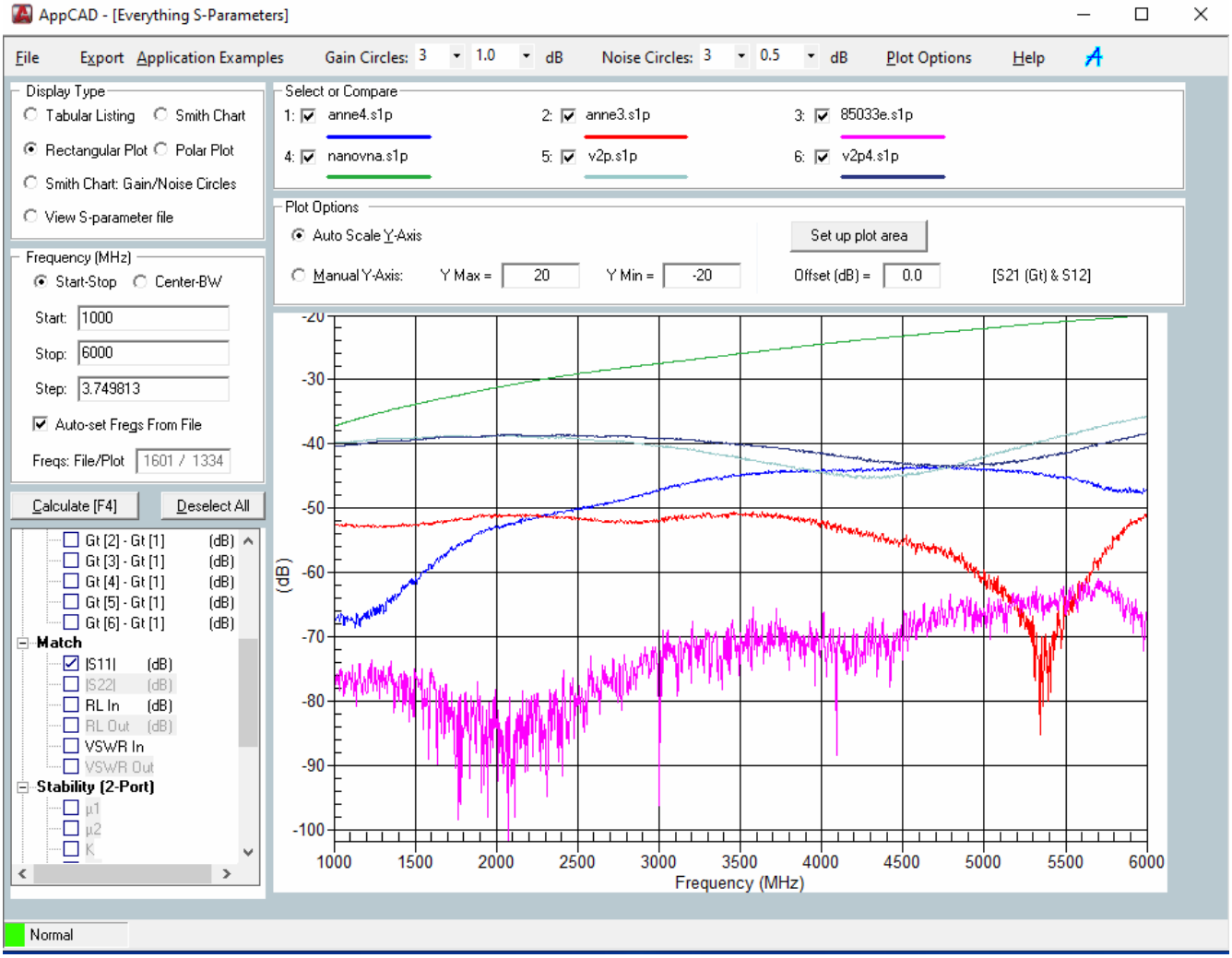

These two Mini-Circuit ANNE's are from a batch of seven that I purchased. I then sorted them based on their return loss. The two shown are the best out of the group. ANNE #3 is what I use as my standard for my lab experiments. For the V2+, the original load was swapped out for ANNE #4.

Shown are some of my homemade standards using various SMT resistors for experimenting up to a GHz.

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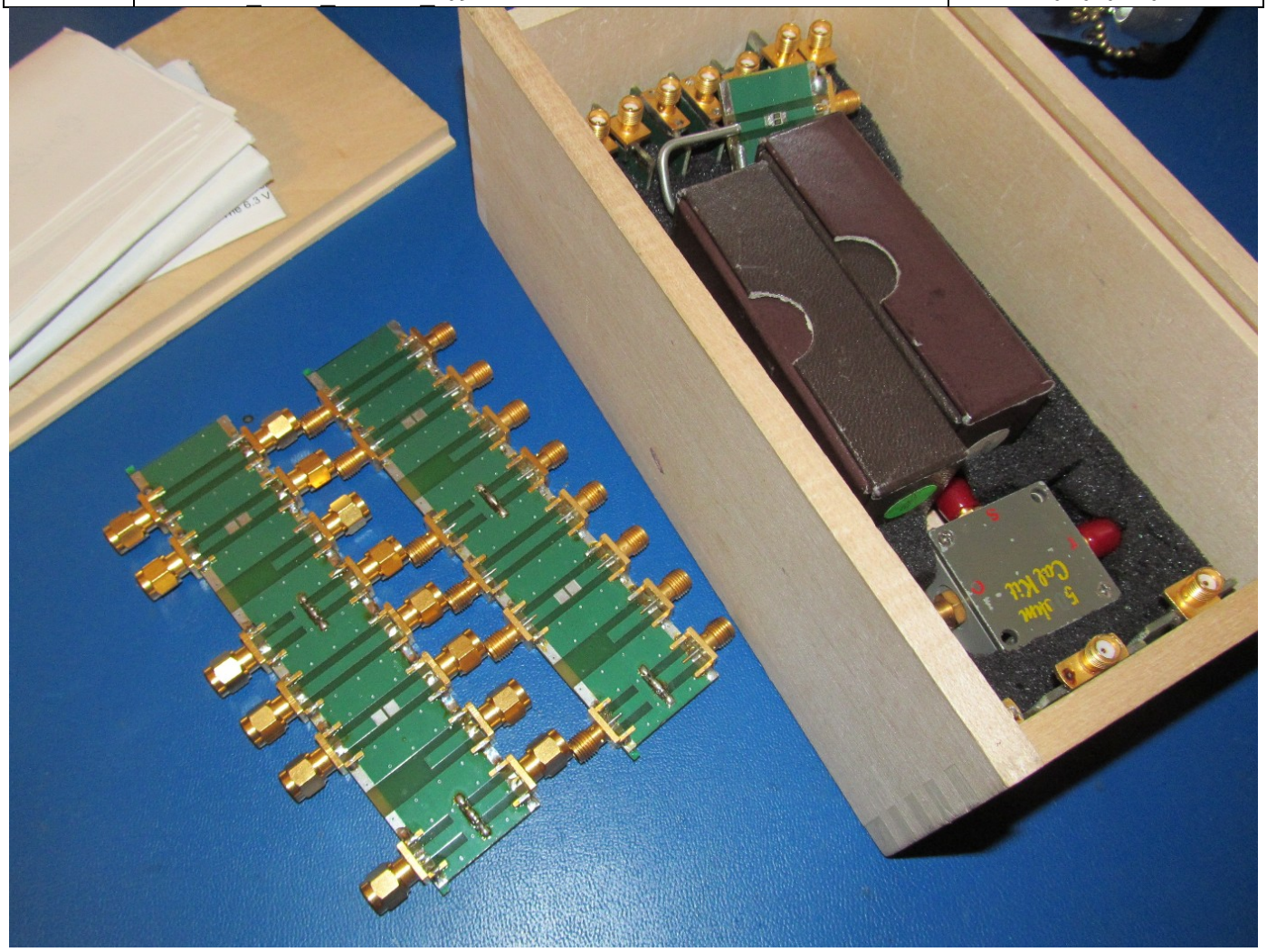

Attempting to make a decent load for 3GHz, good luck with that! I have attempted to make standard's for use above 1.5GHz in the past and the only thing I have accomplished is wasting time.

Shown below was an attempt at making a set of TRL standards using some RG401 semi-ridgid coax from Fairview Microwave, PN# FM-SR250ALTN-STR.

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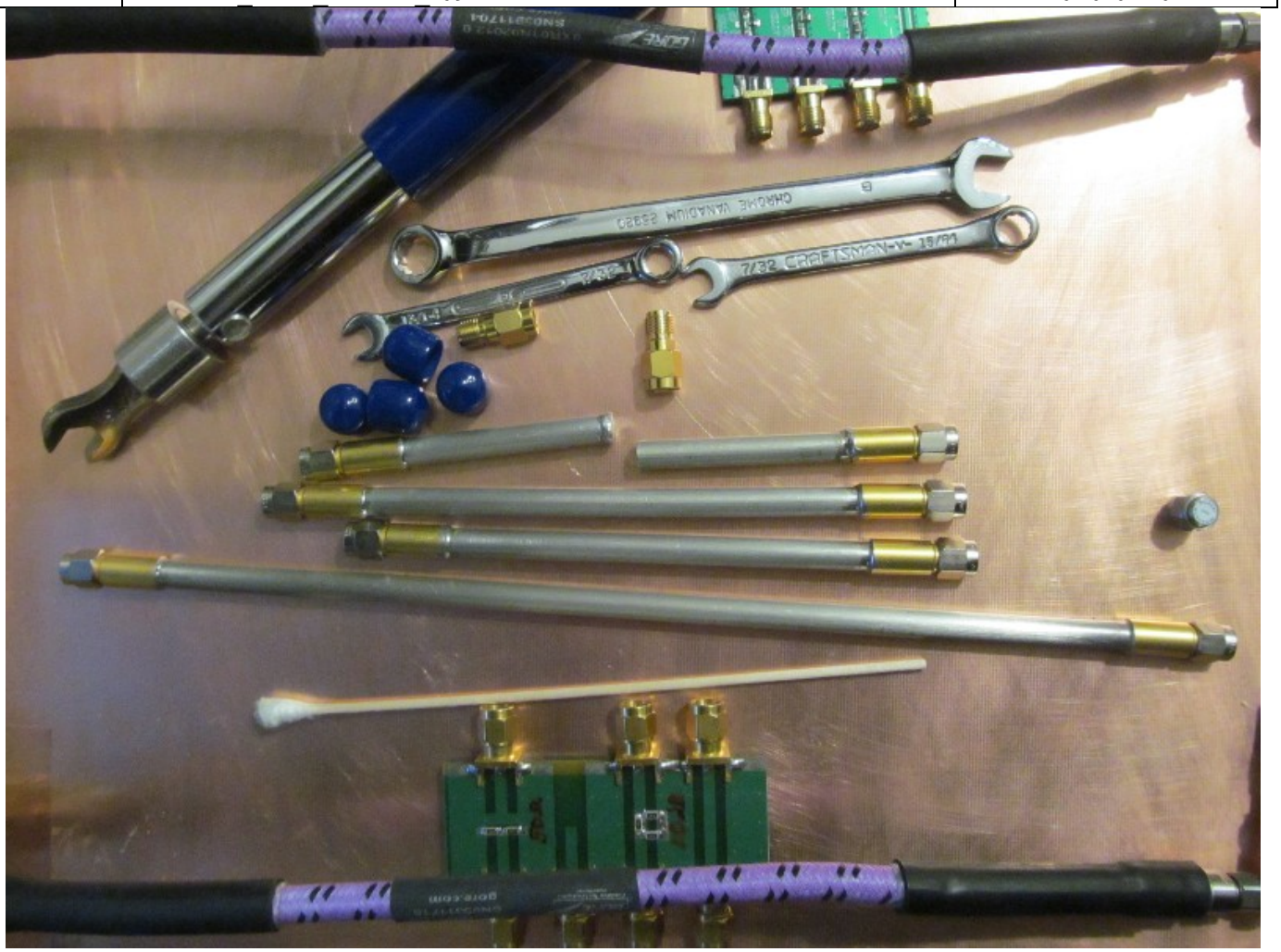

Shown below are some of my homemade standards for experimenting in the GHz range. Toward the left are the N and SMA standards. These were characterized using a set of HPAK standards.

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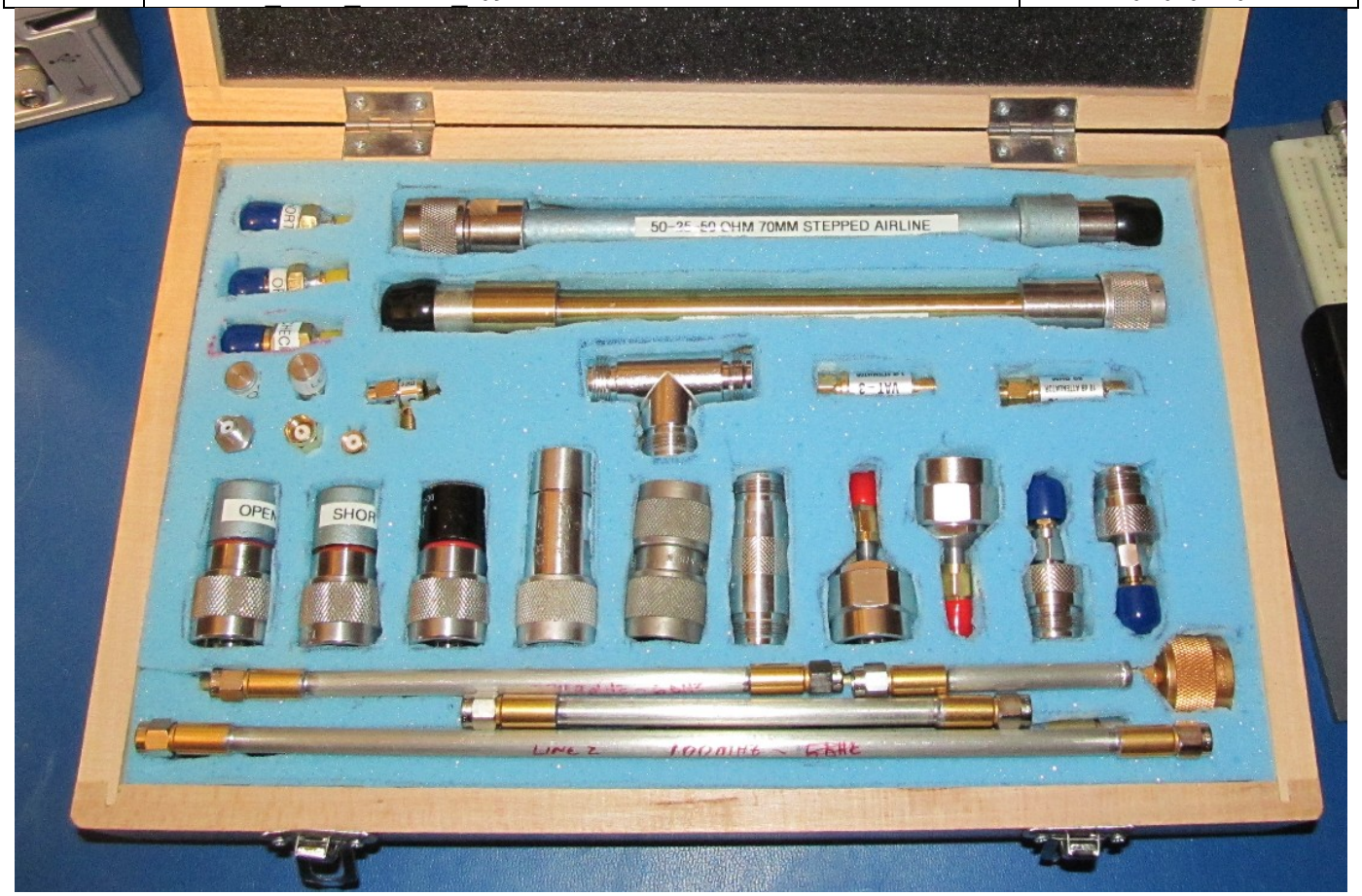

The N type were made from some old Narda terminators. Machining the parts for these took several attempts. The T-Check shown (upper left third down) was a improvement over the original PCB style and yields good results to around 2GHz.

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Don't expect to just go out and buy a new part from Mini-Circuits and replace yours. They need to be characterized as their tolerances can vary a fair amount.

- defense & radar

Electrical Specifications T_{AMB}=25°C

FREQUENCY (MHz)	IMPEDANCE (OHMS)	RETURN LOSS (dB) MIN.				POWER RATING* (W)
		DC-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	
DC-18000	50	30	27	23	21	1.0

*At 50°C, derate linearly to 350mW at 100°C.

Typical Performance Data

Frequency (MHz)	Return Loss (dB)
100	51.21
1072	43.38
2024	38.95
2800	36.93
3400	35.82
4000	35.20

ANNE-50+

CASE STYLE: LL561

Connectors	Model
SMA-Male	ANNE-50+

Features

- wideband coverage, DC to 18000 MHz
- return loss, 35 dB typ. up to 4000 MHz and 27 dB typ. 10000 to 18000 MHz
- rugged construction

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Sorting the terminators is not trivial. Show below is one of my vintage VNAs along with a set of HP standard's that were used to characterize my home made N standards.

Another set of Agilent standards used to characterize my 3.5mm set.

Of course these standards were never used with the NanoVNA. They are a metrology grade and demand care.

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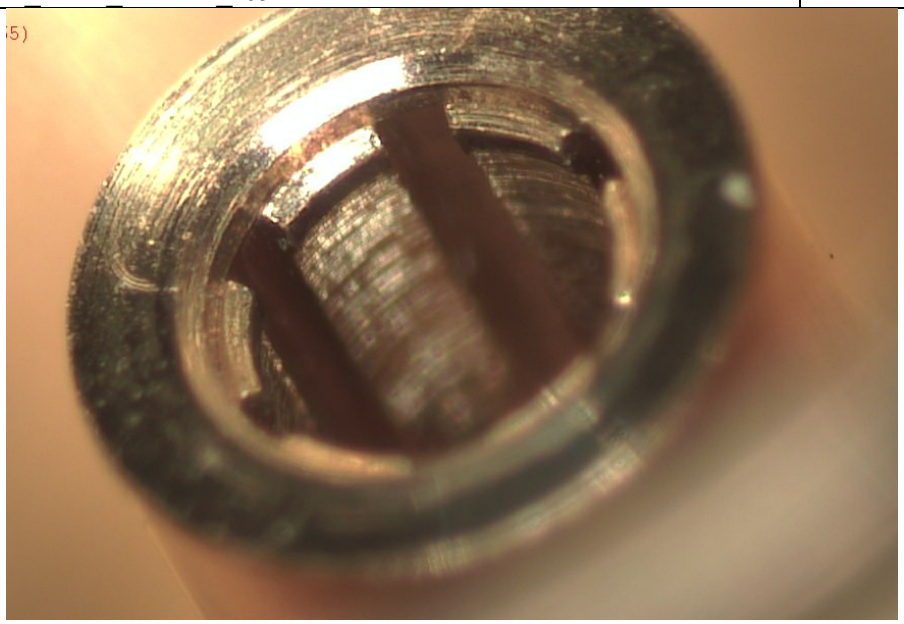

Shown is the new thru with a flat and ANNE included in my V2+ cal kit. On the far left it the original short. There was not enough of the center exposed to be able to hold it without twisting the center pin. I machined up a 5/16” nut from brass hex stock and soldered it to the back side. This allows the use of a standard wrench to be used with it. A much needed improvement.

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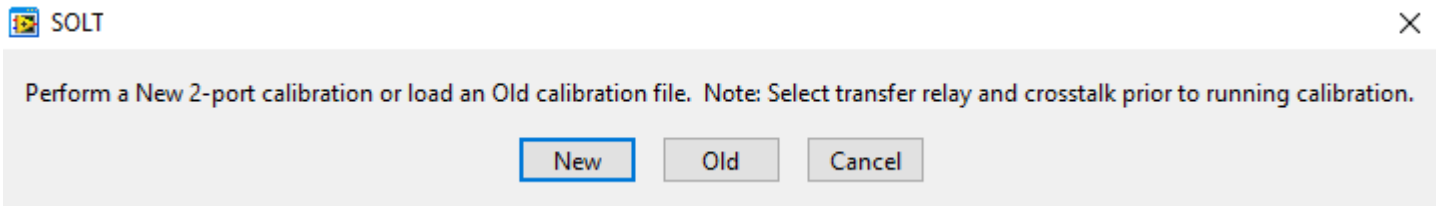
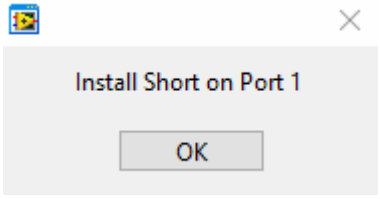
10.8 SOLT Calibration

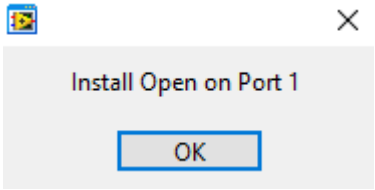
For this experiment, we will use the included cables and modified calibration kit. Select CHn-Ref to disable the normalization. Next select the 2PortCal. You will be prompted to create a new calibration or load a previously saved one. You can have as many calibration files as you want. If you had a previously loaded calibration and you select Cancel, it will purge the current calibration.



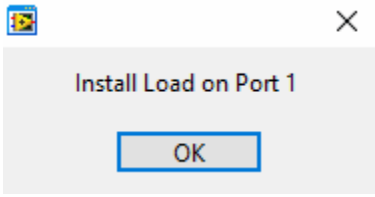
Select New. You will be prompted to insert the short on Port A (Port 1).



After you have it properly installed (cleaned, torqued…) go ahead and select OK. The software will prompt you to install the Open standard.



Replace the short with the open and select OK. The software will measure the crosstalk during this time and will then prompt for you to install the load.



Again, select OK after installing. Now install the thru.

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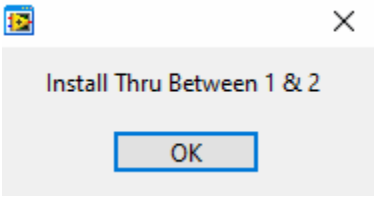
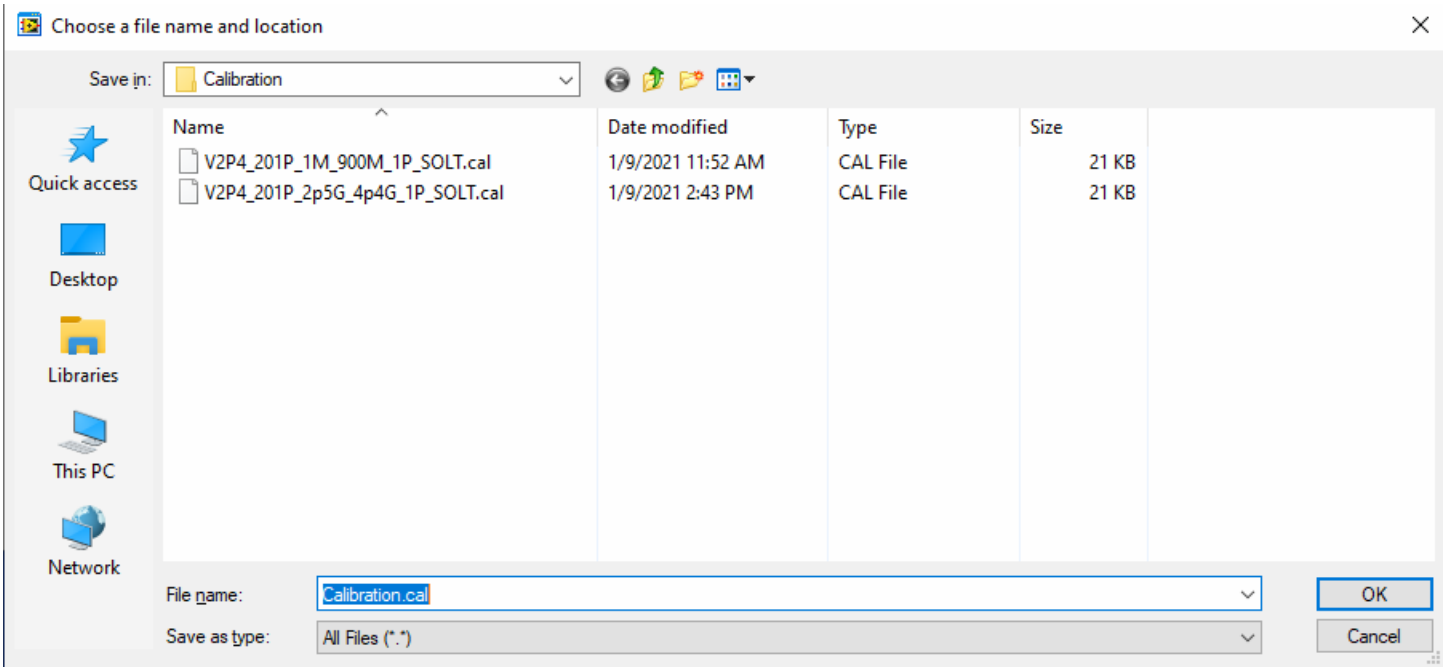


This software has the ability to control a transfer relay. If this option was enabled prior to selecting the calibration, you would be prompted to repeat this process for port B (2). After collecting the data, the software will request you to enter where you would like to save this new calibration. It defaults to Calibration.cal. I like to use descriptive names. As shown, you can see I will include the start and stop frequencies in the file name. I also keep the calibration files in a separate directory.



Select OK. With the thru still installed, select the rectangular transmission function.

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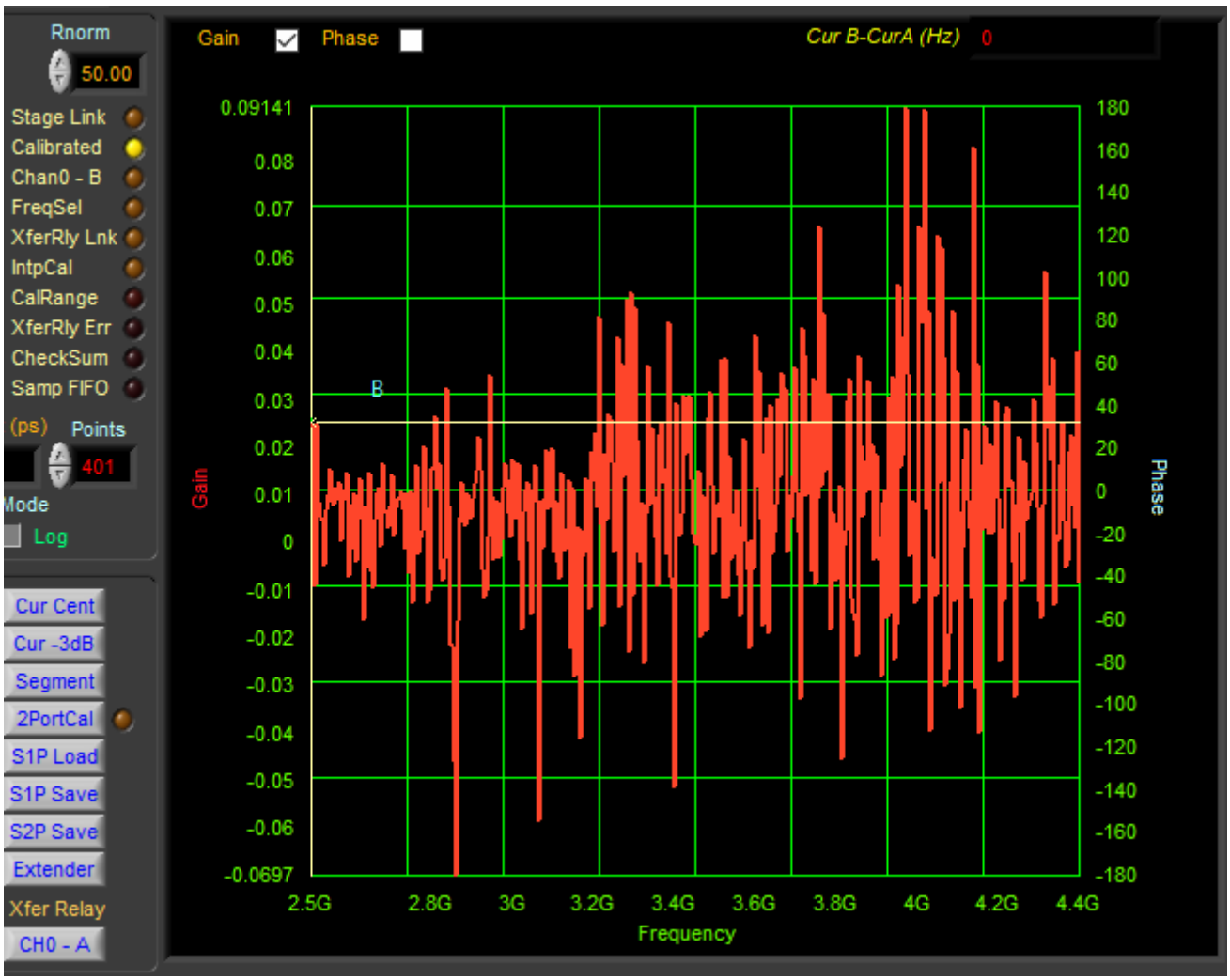
The software now shows the V2+ is calibrated. As we can see, with no normalization the V2+ is now showing < 0.1 dB of error.



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Next the Midwest Microwave 30dB attenuator was inserted. The data doesn't look very good but remember, I mentioned the problem with cross talk at these higher frequencies.

Before moving on, let's save this data to memory by selecting MS1.

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Select the Setup/Diagnostics menu and then select the Calibration Terms submenu. Now select the Leakage Terms checkbox.

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After you have selected Leakage Terms, return to the main menu. Notice now that our attenuator is now within 2dB all the way up to 4.4GHz.

Of course, you may be curious if this is correct or not, so here is the same attenuator shown on one of my old VNAs using my own home made calibration kit.

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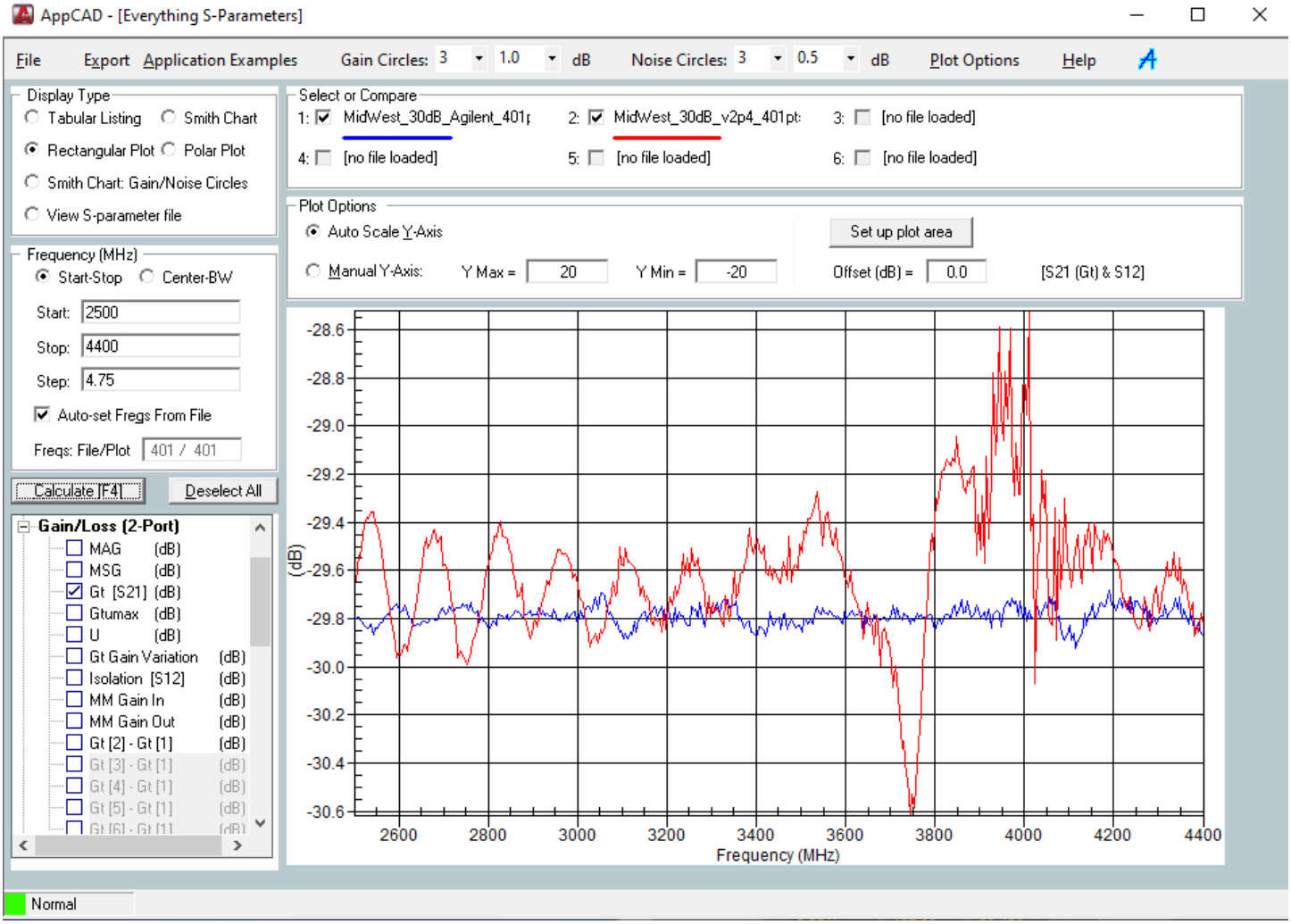
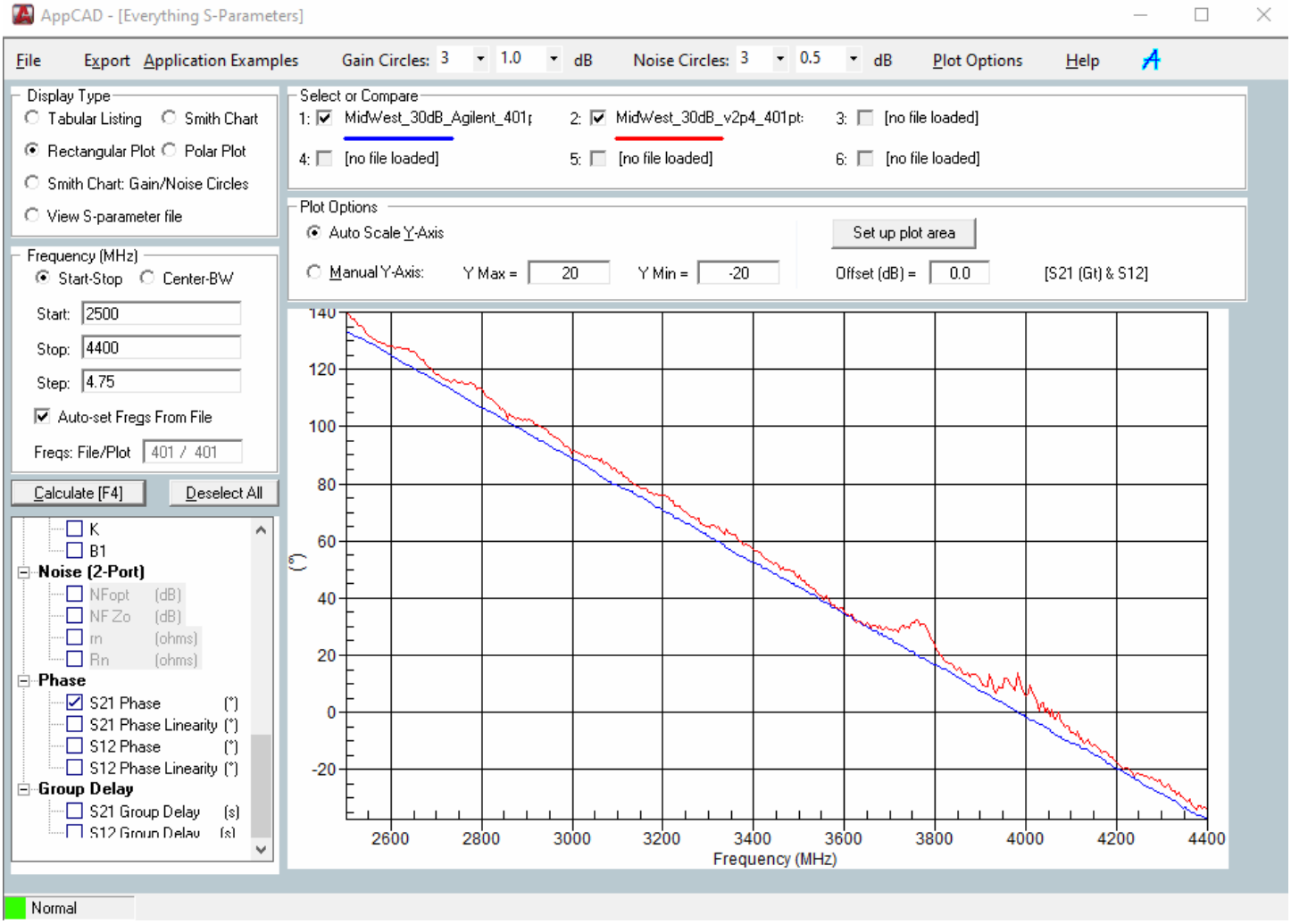


PROPRIETARY: Information contained within is subject to the notice on the cover page of this document.



Now let's install our very low cost 30dB attenuator. It's not much better but again, it's a $5 part and rated for 4GHz with a 1.5dB flatness. The author has purchased two different versions of these low cost attenuators. One of them performed much closer to the claimed specification.

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10.9 Interpolation

The software will now perform an interpolation of the calibration data if the frequency is changed rather that requiring a new calibration be performed. This is done automatically if the frequency bounds have changed by more than 20KHz. The new frequency range must be within the range that the unit was calibrated. If for example we set the start and stop frequencies to 1 and 300MHz, then perform a calibration. We can now change the start and stop to anything within that range. For example, we can change the start to 20MHz and you will not have to recalibrate. The software will activate the IntpCal indicator to let you know it is using interpolation.

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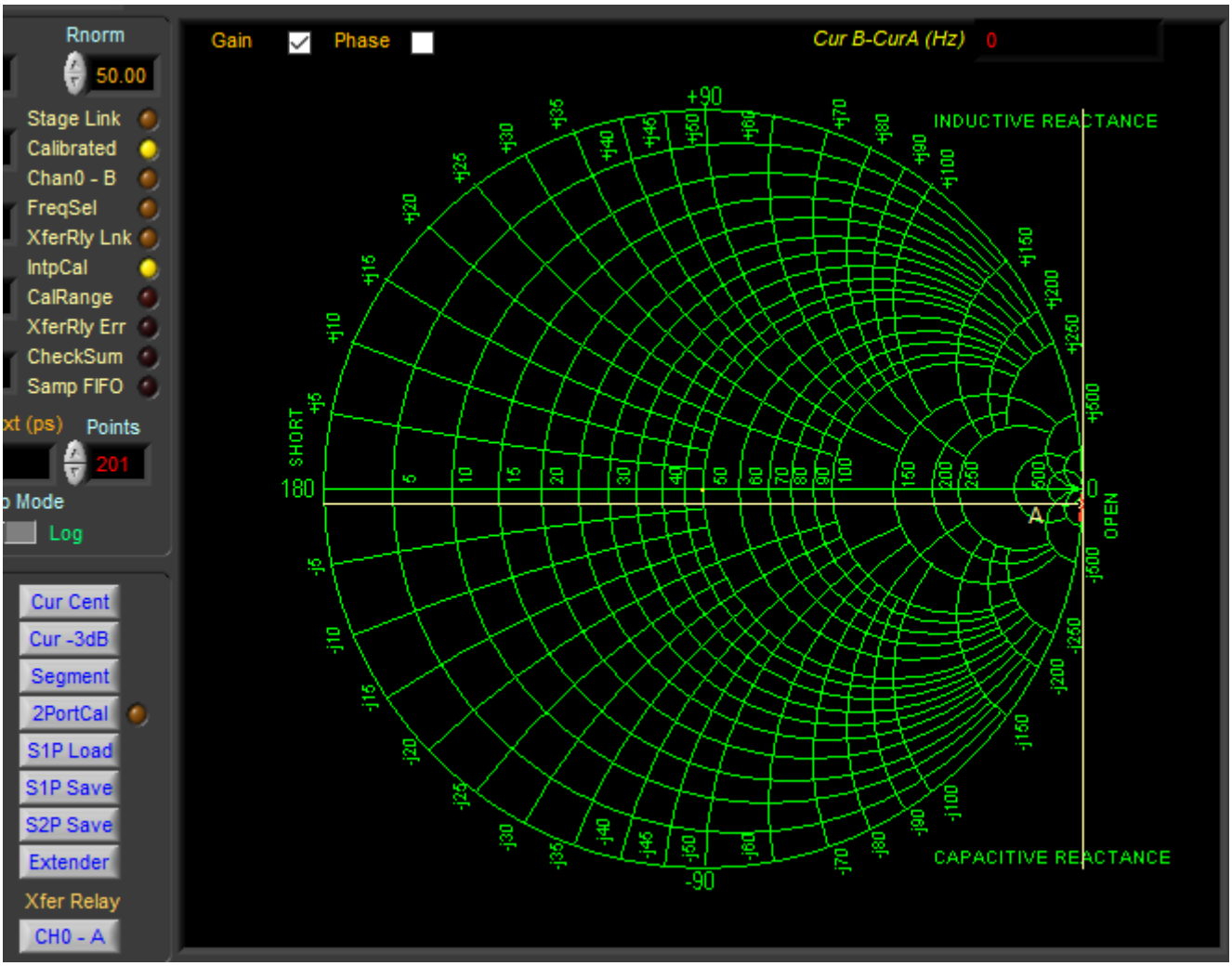

If you change the start back to within 20KHz of the frequency the unit was calibrated, the IntpCal indicator will turn off along with interpolation. If you do go outside of the calibrated range, the software will activate the CalRange error as shown below.

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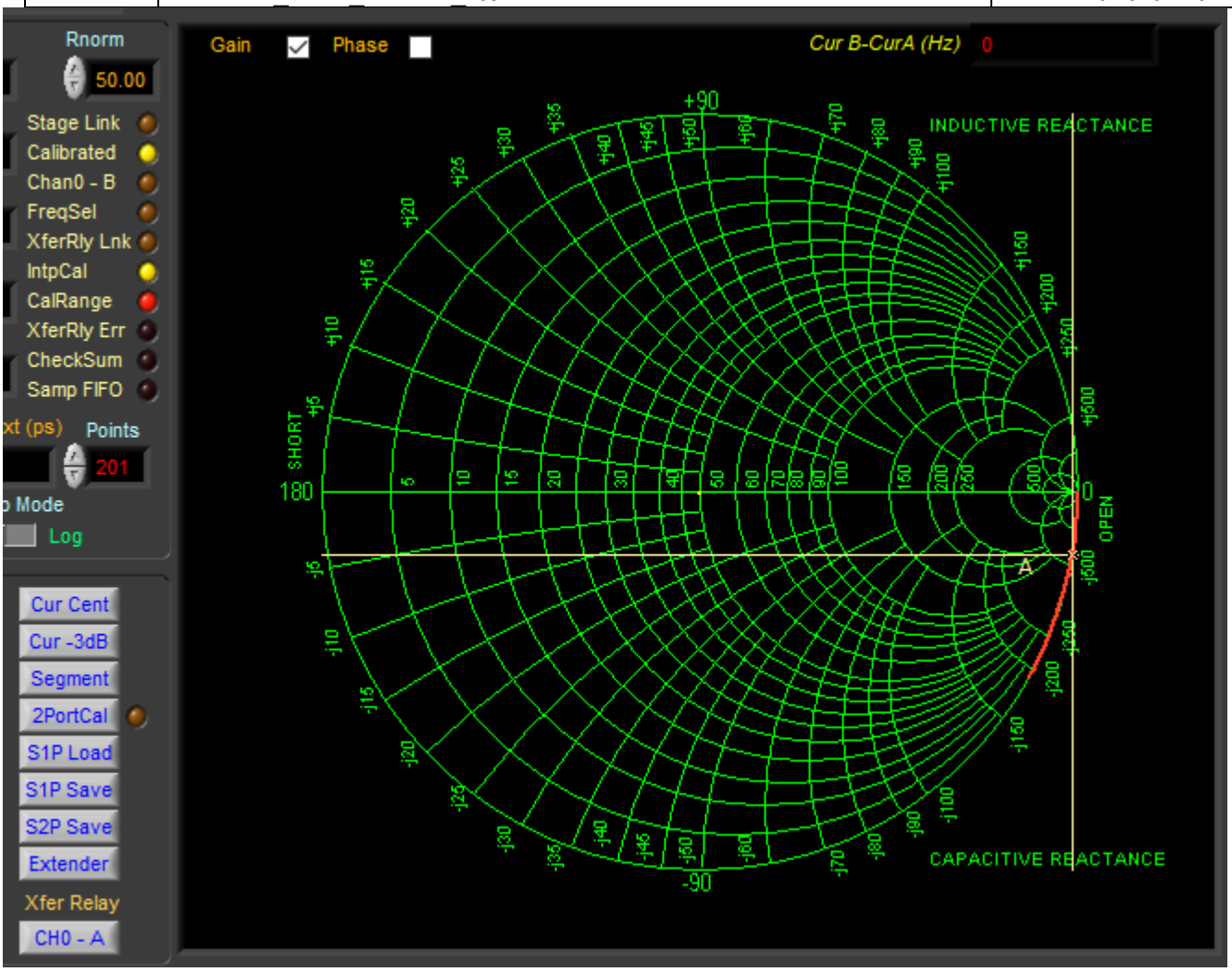

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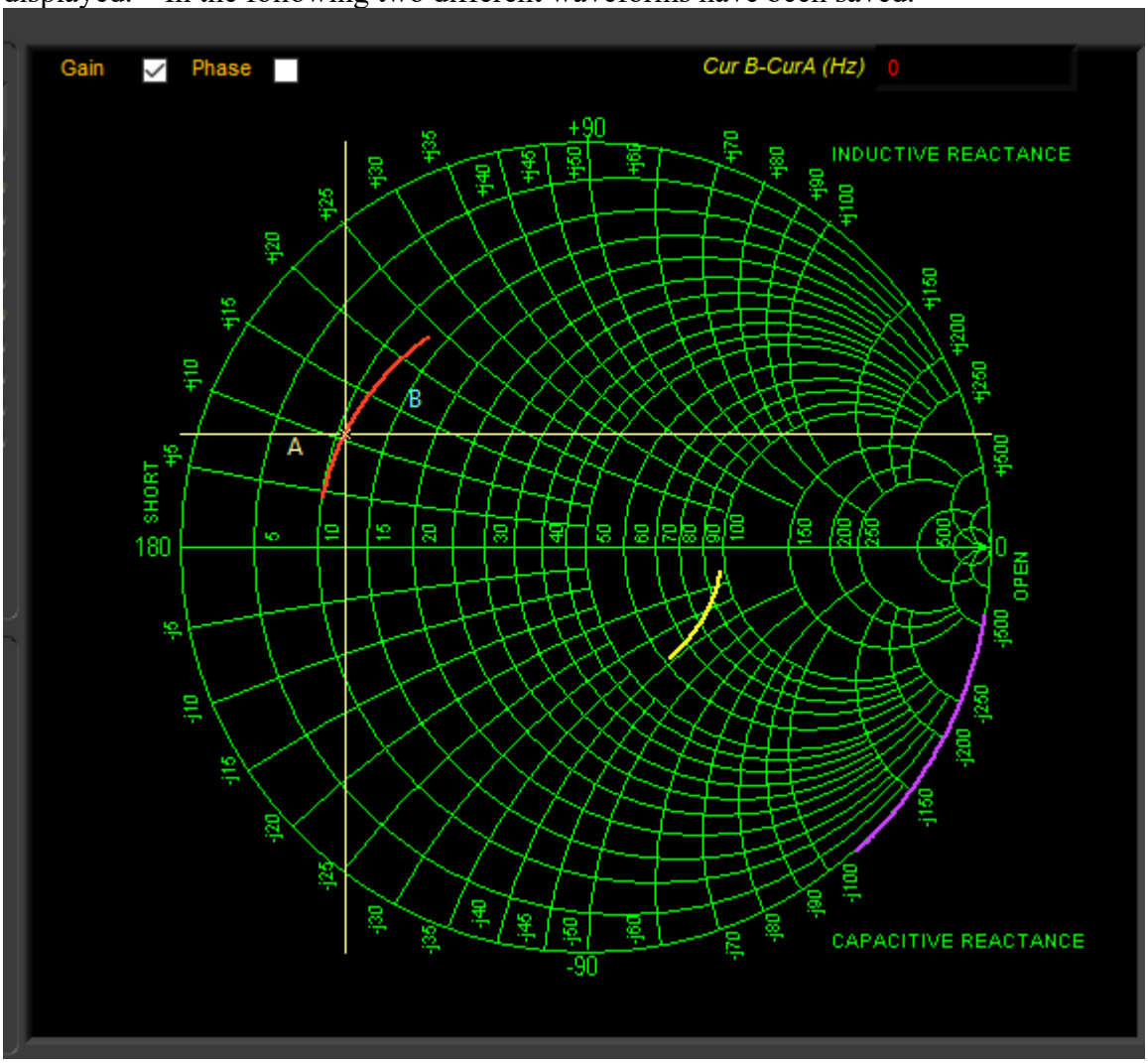
11. Using Memories

The software has three memories that may be used to temporarily store and overlay waveforms. The Ref and CHn-Ref is a special memory that is used to normalize the data. MS1&2 have no math functional associated with them.

Store the current waveform by selecting one of the two buttons, MS1 or 2. The waveform will be immediately displayed. In the following two different waveforms have been saved.



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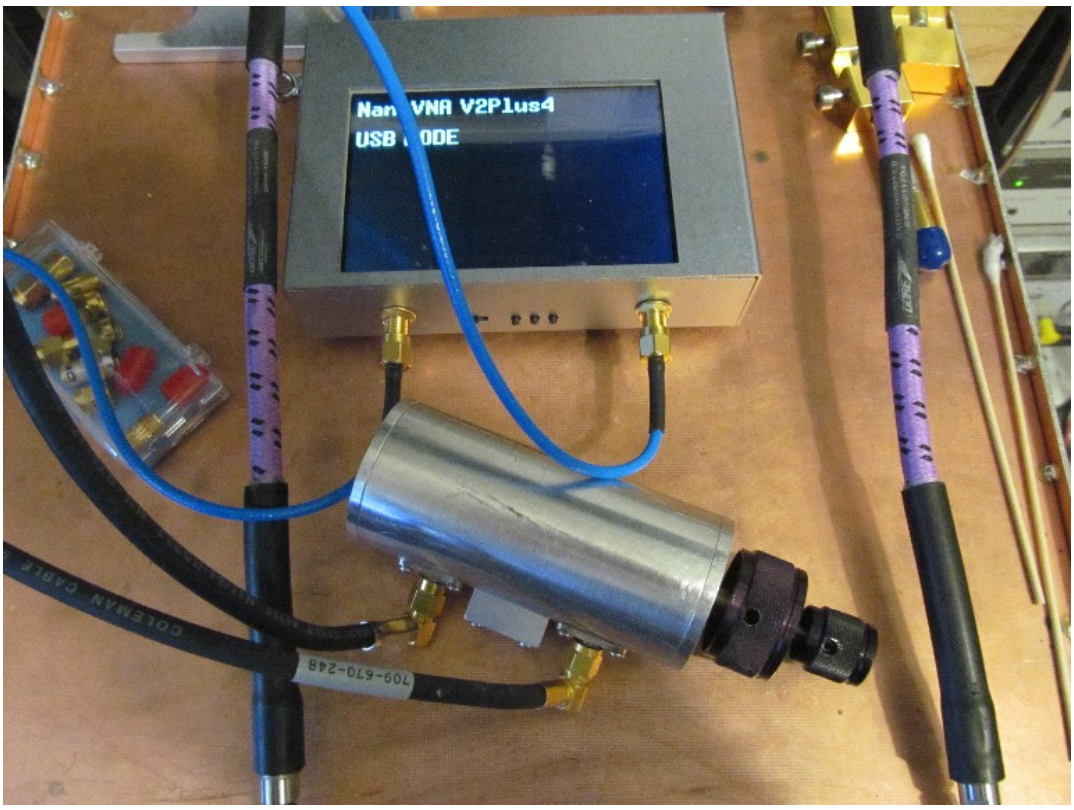
The memories will work for both polar and rectangular measurements. Here we have installed a manual step attenuator.



We have saved 0dB into Mem1 and 10dB into Mem2. The attenuator was then set to 20dB.

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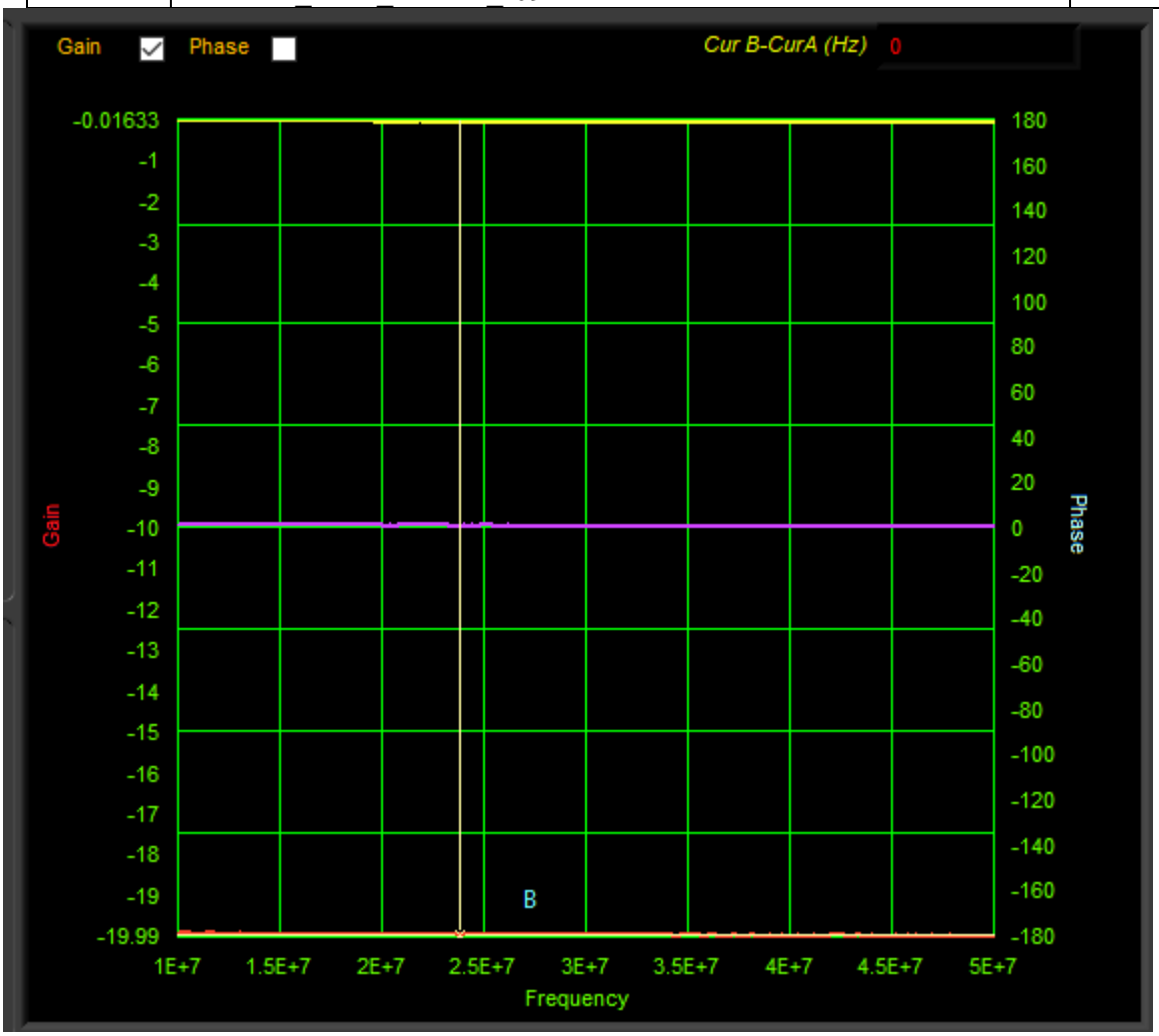

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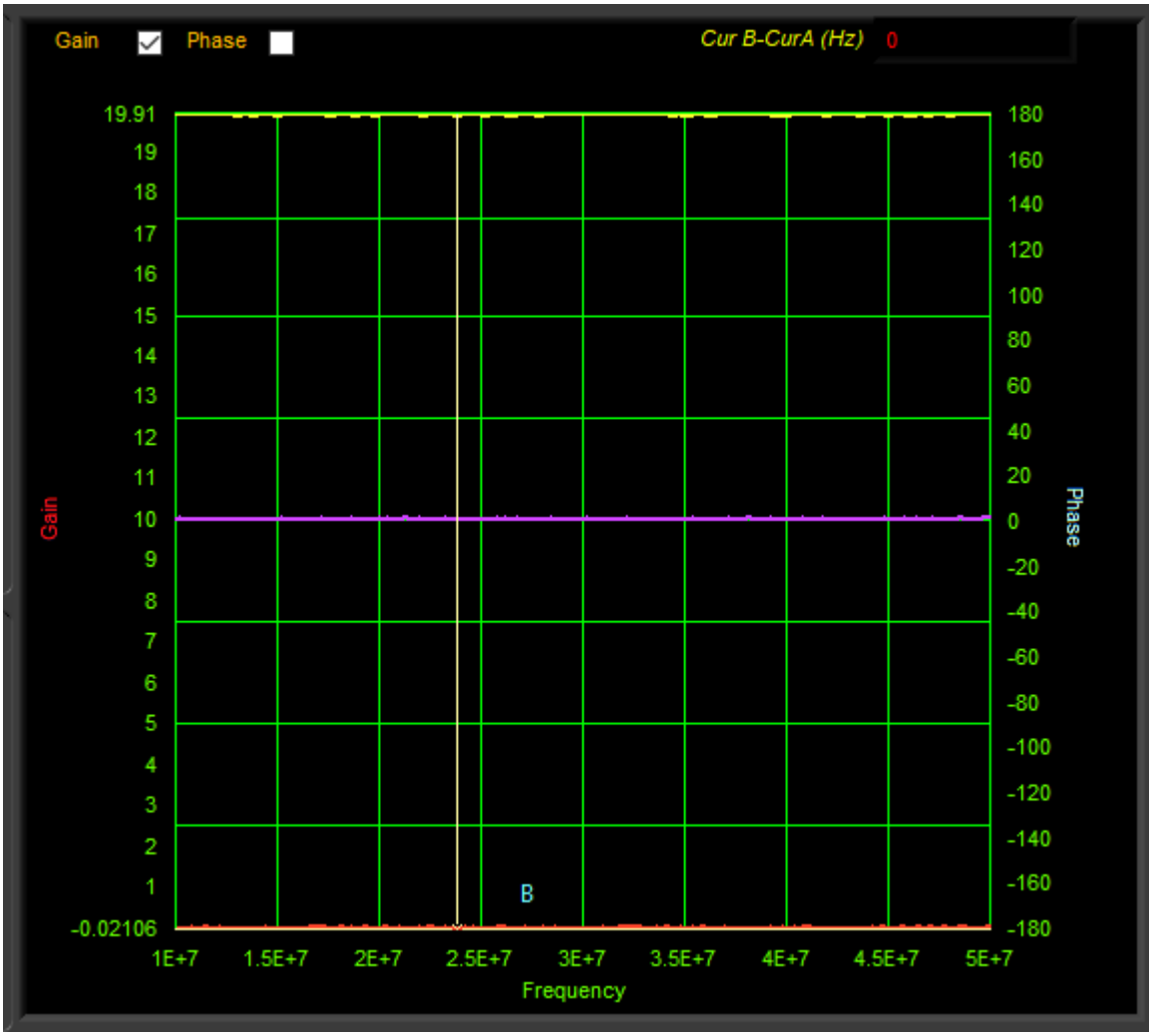
If the Ref is selected, it will save 20dB as the reference. If we select CHn-Ref, the software will apply the reference to current sweep as well as the saved data in each memory.



Selecting the clear button will erase all three memories and turn them off. You do not have to erase a memory before storing a new waveform to it. Pressing one of the memory keys will always overwrite the previously stored waveform.

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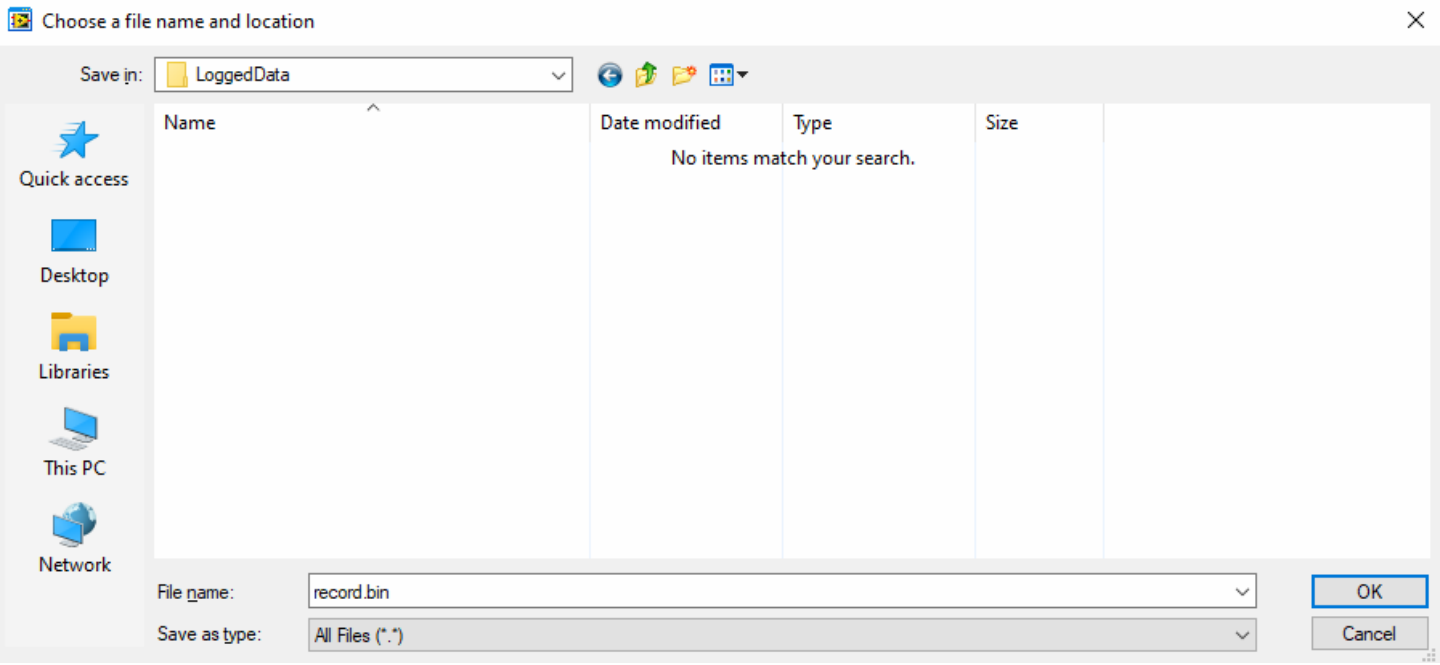
12. Recording Multiple Sweeps to Disk

The software has the ability to record the swept data to disk. Once you have the VNA setup, select the Record button. You will be prompted to enter a filename.



The software will immediately begin recording all of the corrected S-parameters. Selecting standards, performing a calibration, changing the port extension, using normalize and enabling filters will all have an effect on the recorded data.

The author has found the V2+ (not the +4 model) to be very unreliable when running for extended times. The NanoVNA itself appears to lockup and will require a power cycle to clear it. The +4 model does not appear to have this problem. You need to be aware of this if you are attempting to run a long term study.

Once you have finished recording your data, just select Record again to stop the collection.

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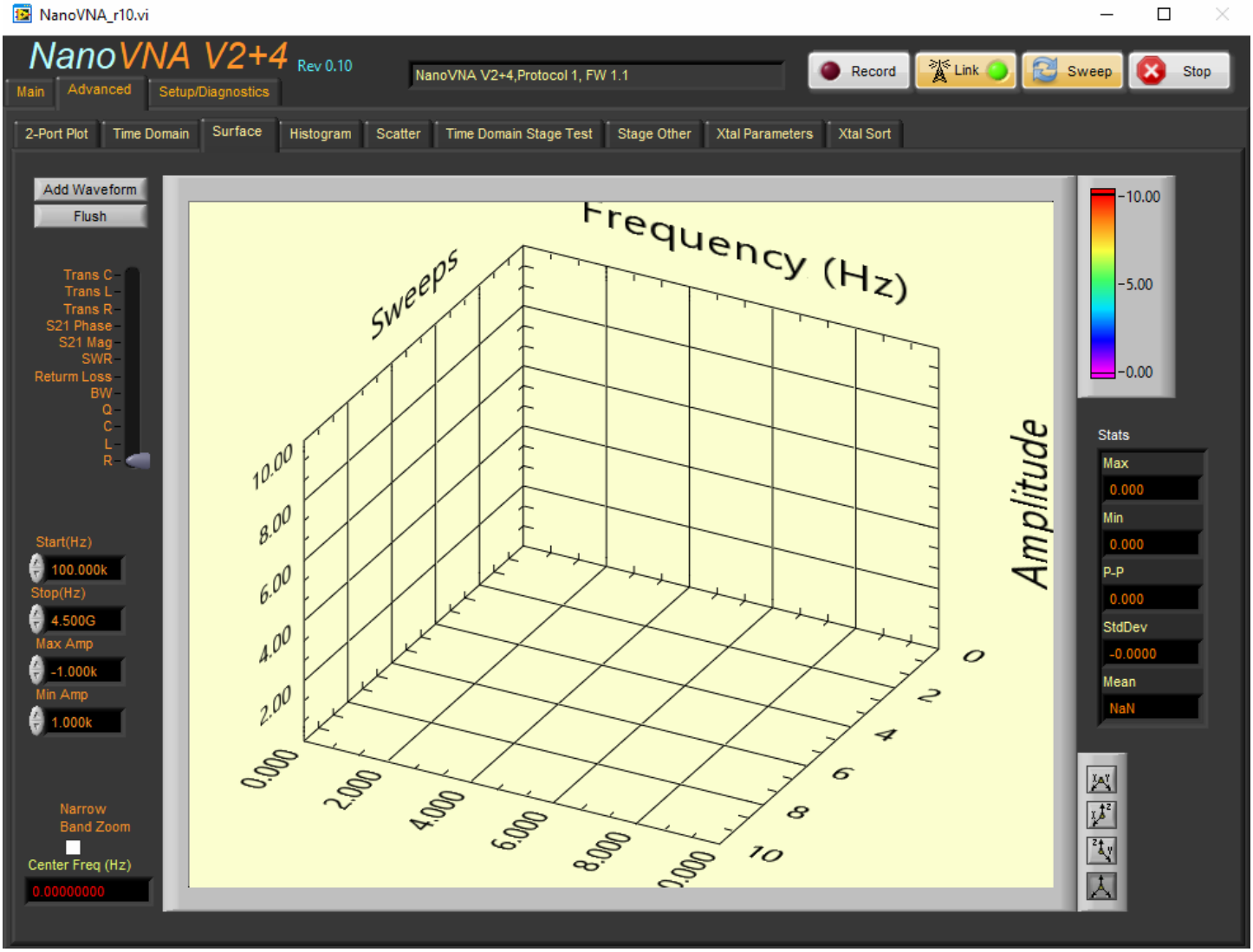
12.1 Post Processing

Selecting the Advanced tab followed by the Surface tab will bring up the following menu.



You may now select your file by selecting Add Waveform. You will be prompted for a file name. Note there is now a file named record.txt which is the file we have just created.

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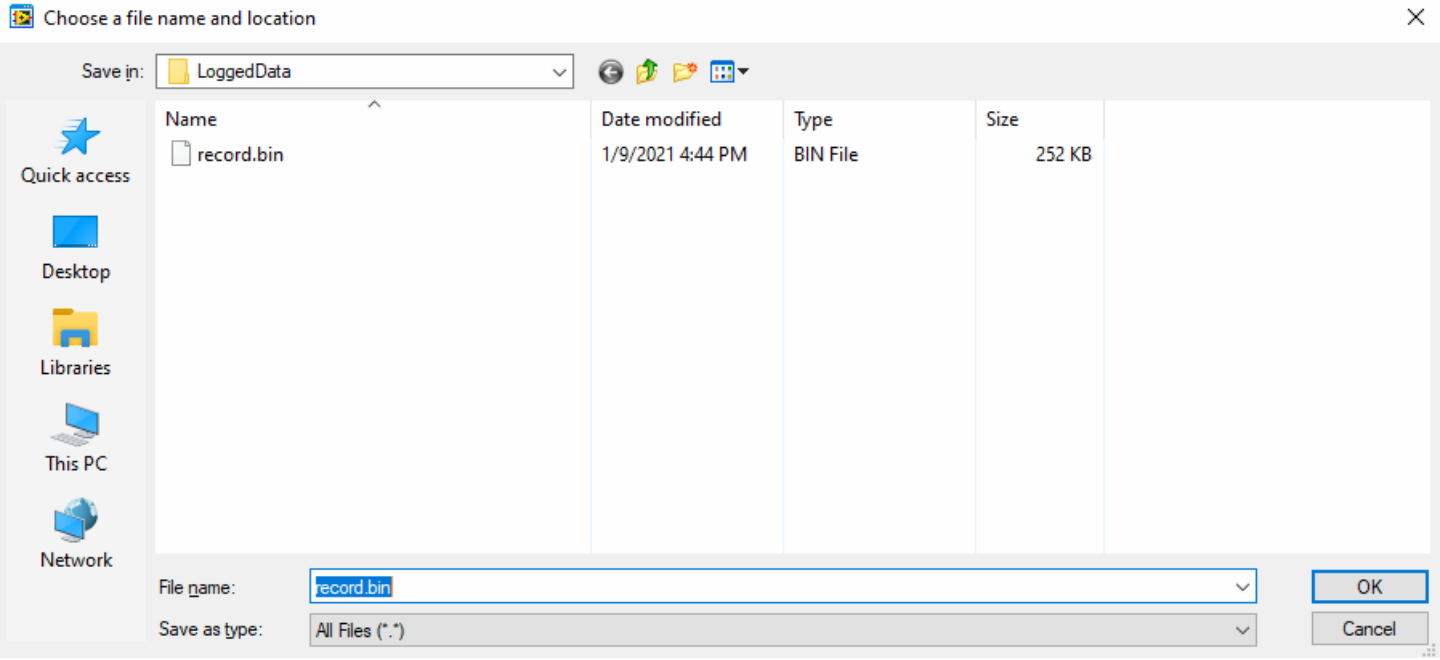

Once the file has been loaded, you may use the slider on the left to select the parameter you would like to view.

IMPORTANT!!!!

This file is not ASCII formatted! The default names where changed to .bin to reflect them being a binary file. Currently, Touchstone is the only ASCII formatted file type supported for swept data.

Selecting Flush will purge the memory.

In some cases we want to view very narrow band data. The Narrow Band Zoom feature allows rescaling the graph about the center frequency. You may also use the Start, Stop, Max and Min amplitudes to change the displayed range of the graph.

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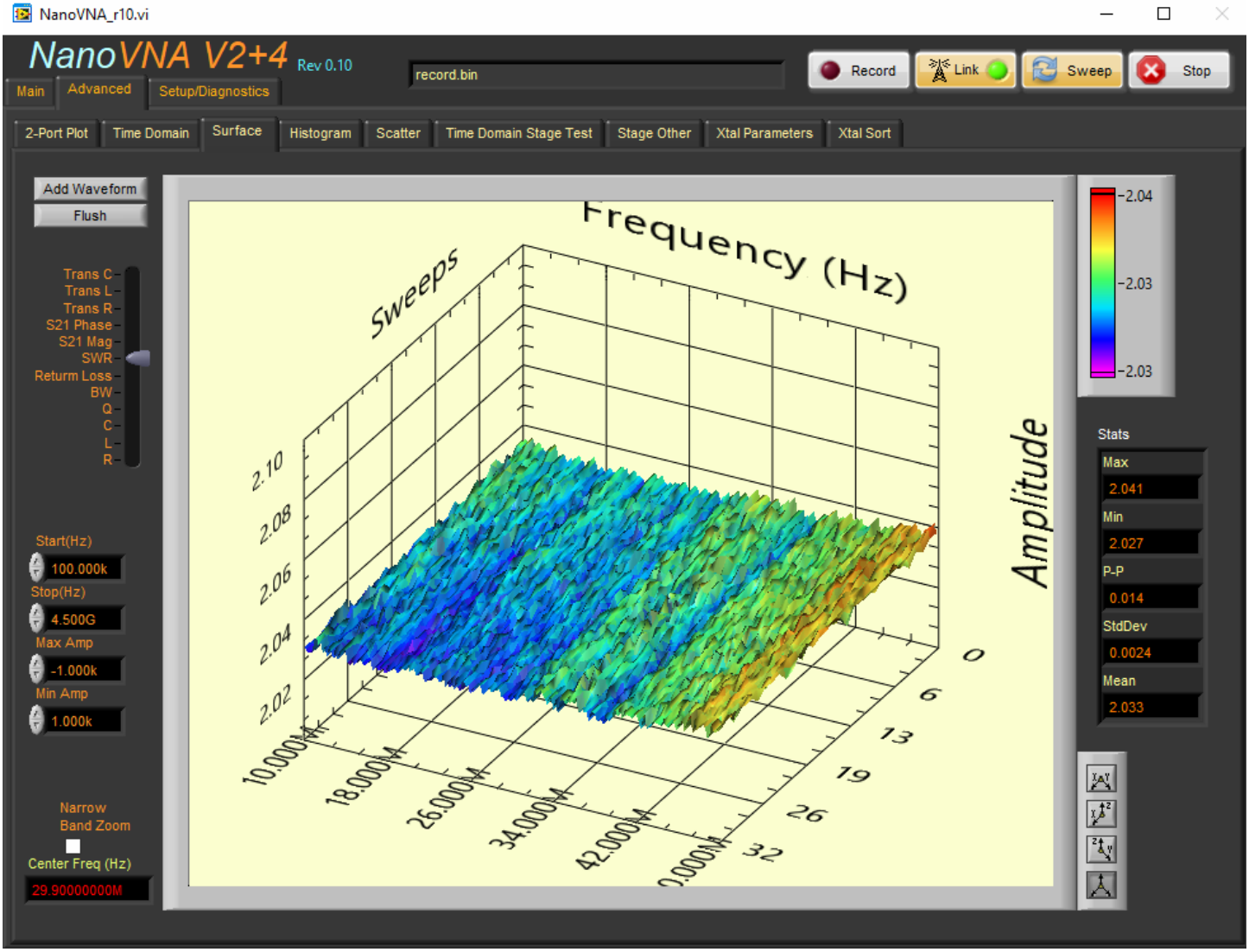

12.2 Histograms and Scattering Diagrams

You may also display the histogram for the selected data.

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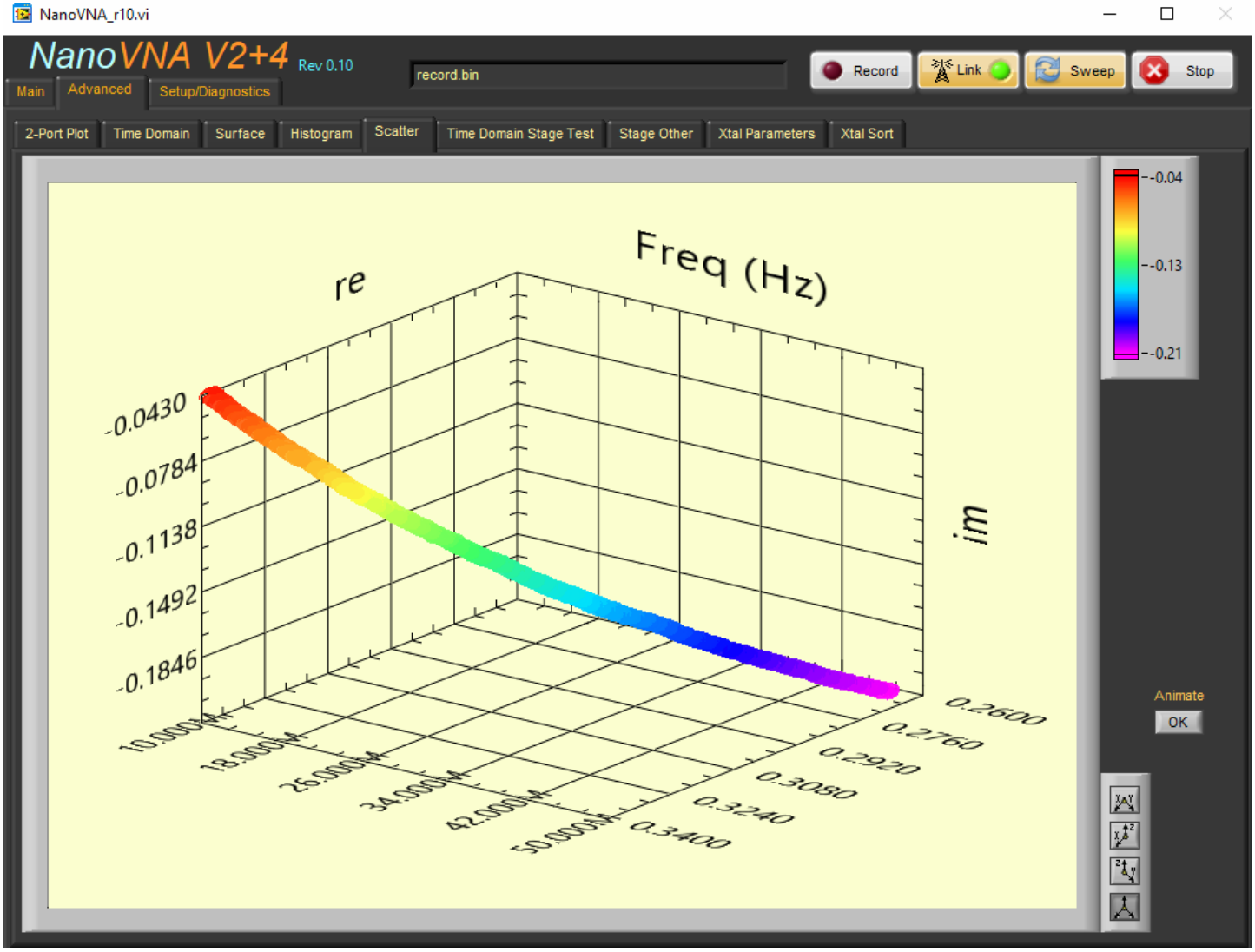

13. Narrow Band Measurements

&$#&%$#%^!!!!!!!!!!!!!!!

While the original NanoVNA did a very nice job making narrow band measurements, sadly the V2+ is not able to make these same measurements. The various features have been included but do not expect them to provide any useful data.

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13.1 Segmented Sweeps

Segmented sweep was originally added to the NanoVNA software to provide a means of creating high resolution Touchstone files that could be used to generate SPICE models. The original NanoVNA supported a fixed 101 data points for a given sweep range. Segmented sweeps provided a way to work around this limitation. The resolution was really only limited by how long the user wanted to wait for their data and the hardware's minimum step size.

The V2+'s native firmware supports more than enough data to make these measurements without the need for segmentation.

13.1.1 Linear / Log Sweep

When using segments, you may select linear or logarithmic sweeps. Linear is fairly straight forward. For log sweeps, the software computes the step size for each segment based on the samples per decade. While not a true log sweep in the sense, it does allow collecting a higher number of data points for lower frequencies.

13.1.2 Setting up the Segmented Mode

Assuming you are running a linear sweep, set Fspan to the frequency range of each segment. The step size is the span divided by the number of data points selected.

Next, set the start (Fmin) and stop (Fmax) to the range of frequencies you would like to sweep.

IMPORTANT!!!!

There is an order to how you select the data. The software will always program the V2+ to the last setting you made. If you change Fcenter, the software will use the center and span to calculate the new range. If you change Fmin, the software will use the min (start) and max (stop) to calculate the range. If you were to program the min and max first, then change the span, the V2+'s start and stop would change.

Also, changing the number of points will cause the software to recalculate the sweep range based on the min (start) and max (stop).

Using the defaults, the software will start by sweeping from 1MHz to 3MHz, with 201 data points. It will then continue to the next segment.

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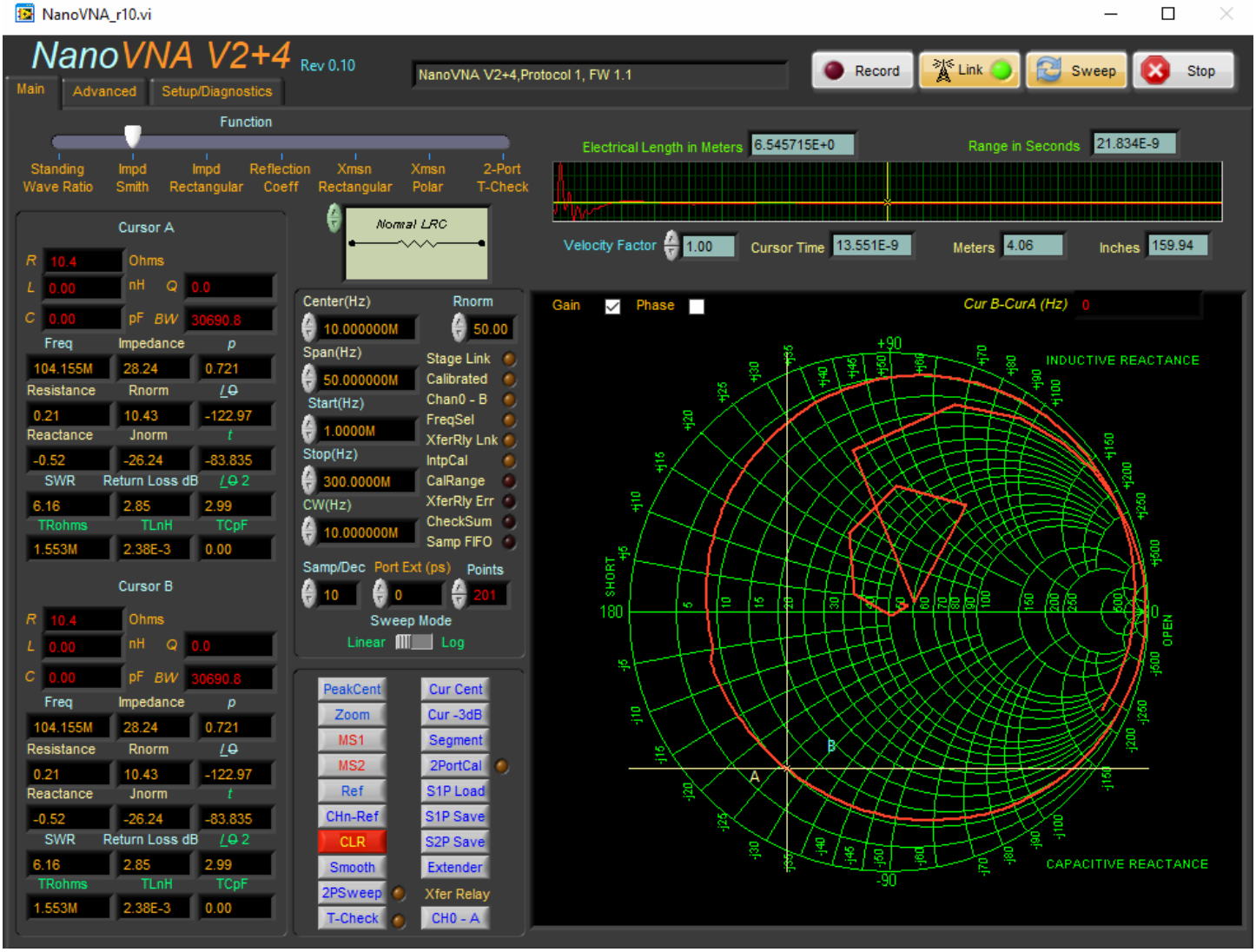
By attaching a 12MHz 5 pole LP filter, we can see that the resolution in the lower frequencies is poor. You can see I have changed the span from 2MHz to 50MHz.



Selecting Segment, we have gone from 201 points to 1005 points. We can now see a lot more detail.

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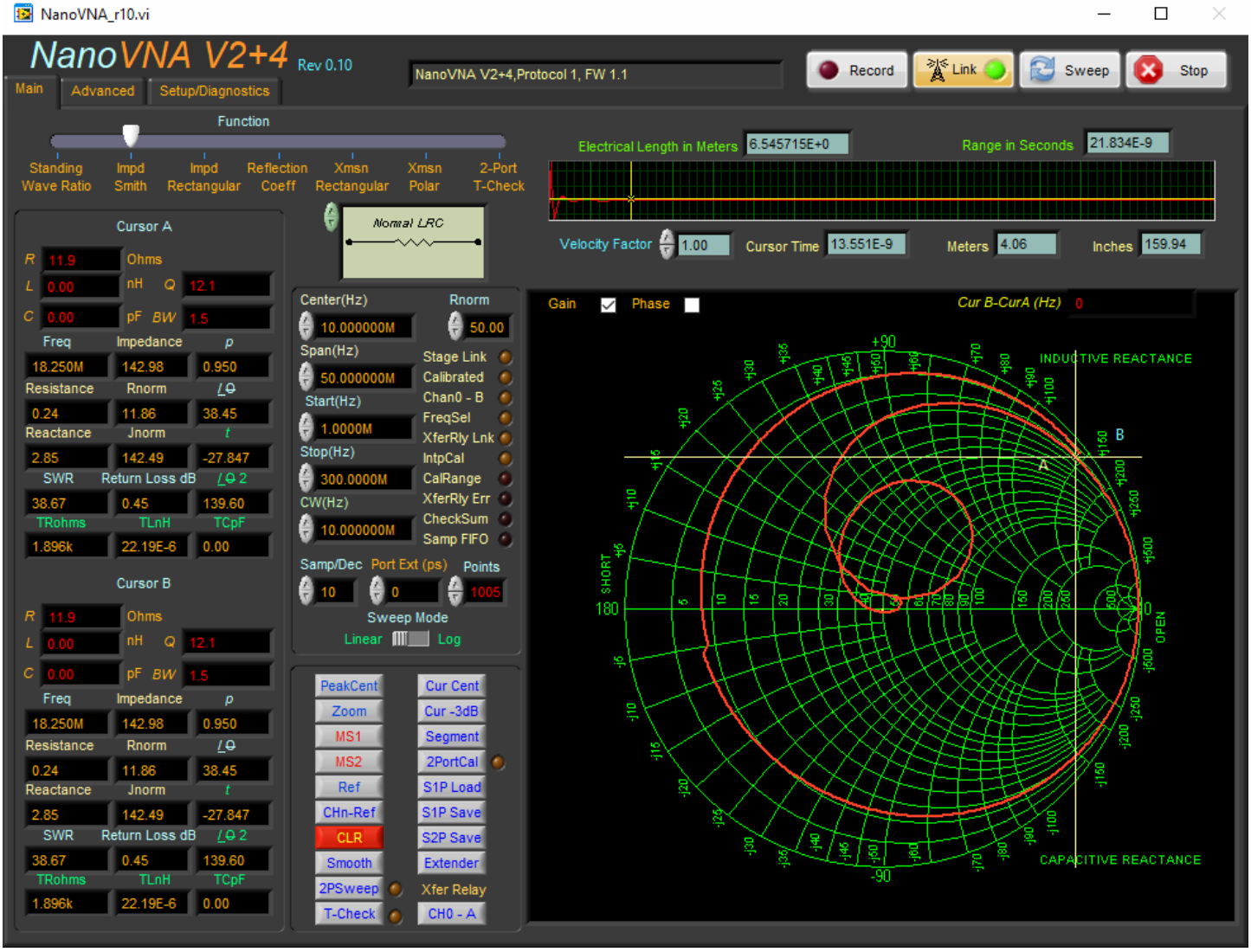

The software currently supports up to 1600 data points. By changing the number of points to 1005 the V2+ will send the same amount of data with a normal sweep.
As shown below, there is no difference between the segmented sweep and the normal sweep. Except that the sweep time in the normal mode is roughly 4.4 seconds.

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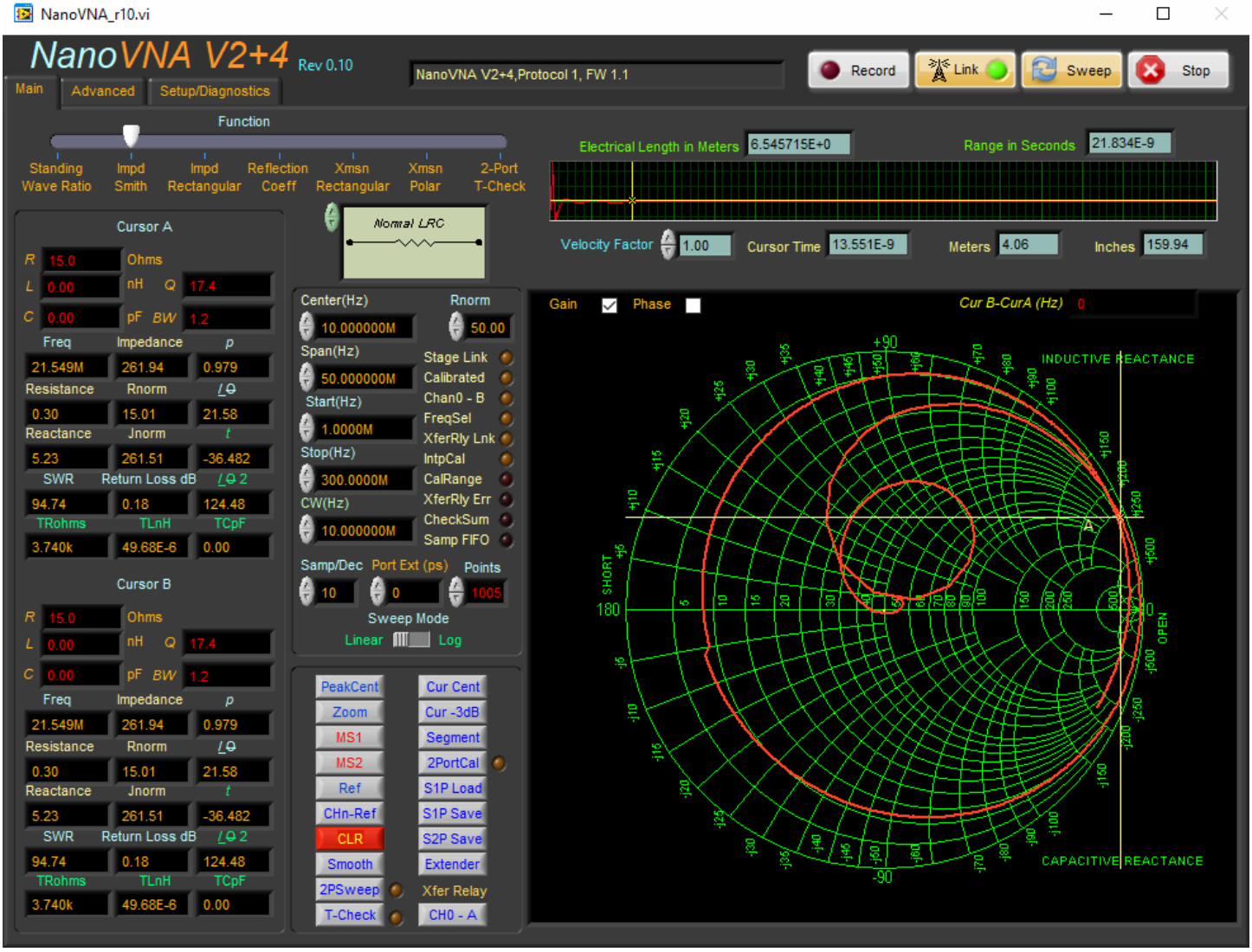

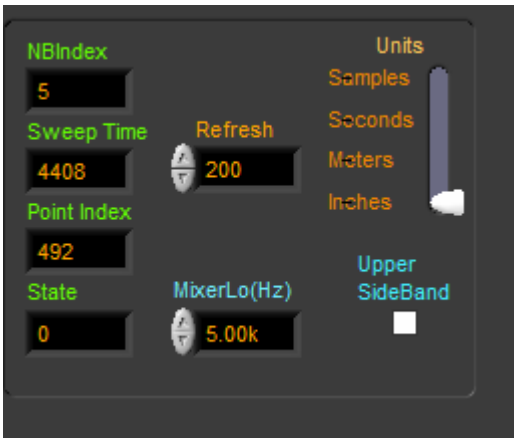

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13.2 Measuring Crystals

While the original NanoVNA made this measurements fairly accurately compared with the author's other VNAs and various equipment, the V2+ lacks the ability to perform any narrowband measurements. This section of the document has been included only to provide details how the software works. Do not expect to make use of these specific modes unless an improved V2+ that is software compatible with the current versions is released.

The following table from CopperMountain shows the equations for the three types of impedance measurements. For these measurements, we will be looking at the crystals series impedance.

1	$Z_0 \cdot \frac{1+S_{11}}{1-S_{11}}$	$\Delta Z^{max} = \frac{2Z_0 \cdot \lvert\Delta S_{11}^{max}\rvert}{\lvert 1-S_{11}\rvert^2}$, $\lvert\Delta S_{11}^{max}\rvert = \lvert D\rvert + \lvert R-1\rvert \cdot \lvert S_{11}\rvert + \lvert M\rvert \cdot \lvert S_{11}\rvert^2$	2.5 Ohm to 1 kOhm
2	$\frac{Z_0}{2} \cdot \frac{S_{21}}{1-S_{21}}$	$\Delta Z^{max} = \frac{Z_0 \cdot \lvert\Delta S_{21}^{max}\rvert}{2 \cdot \lvert 1-S_{21}\rvert^2}$, $\lvert\Delta S_{21}^{max}\rvert = (\lvert T-1\rvert + \lvert M\rvert + \lvert L\rvert) \cdot \lvert S_{21}\rvert + \lvert X\rvert$	1 mOhm to 100 Ohm
3	$2Z_0 \cdot \frac{1-S_{21}}{S_{21}}$	$\Delta Z_3^{max} = \frac{2Z_0 \cdot \lvert\Delta S_{21}^{max}\rvert}{\lvert S_{21}\rvert^2}$, $\lvert\Delta S_{21}^{max}\rvert = \lvert T-1\rvert \cdot \lvert S_{21}\rvert + \lvert X\rvert$	8 Ohm to 100 kOhm

13.3 Test Fixture

To make these measurements, a custom test fixture was created. This is nothing more than two 3dB attenuators and two ten-turn bifilar transformers wound with Teflon wire. This fixture works fairly well for measuring crystals in the range of 2-30MHz.

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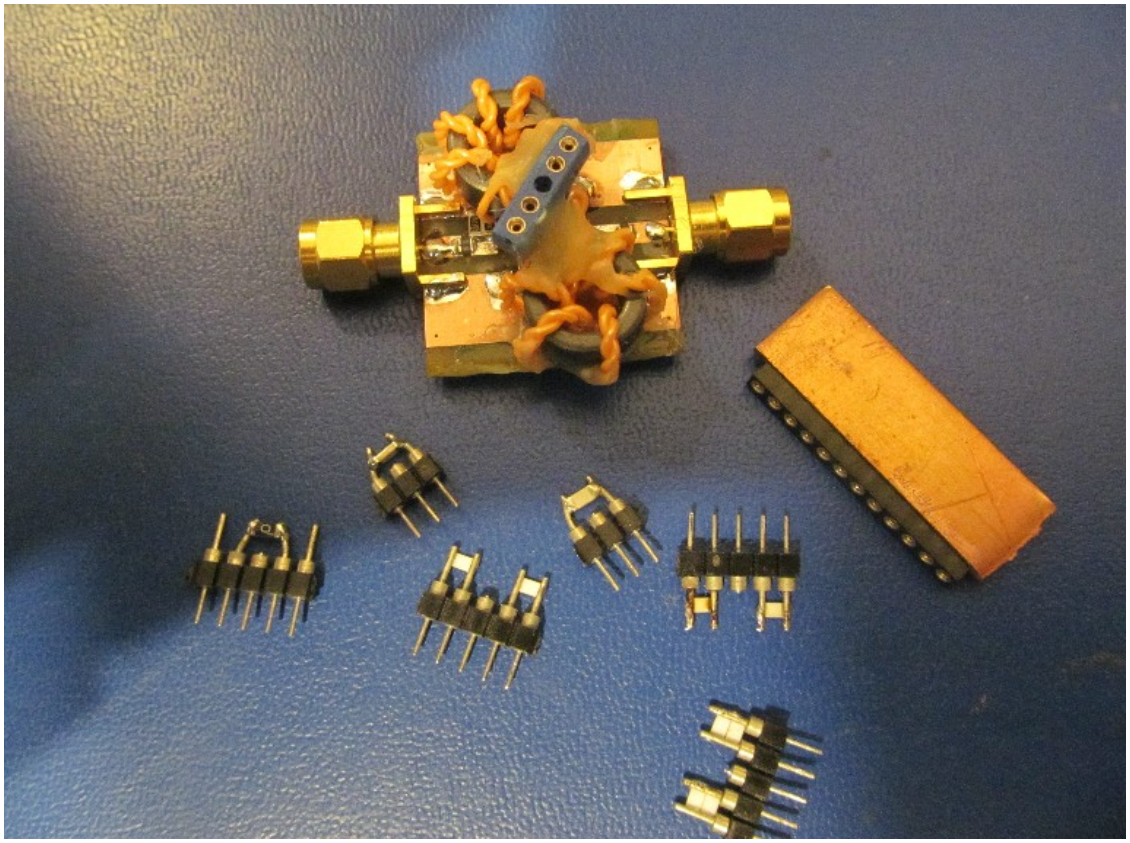
The standards along with the fixture are shown below. The copper block and connector is just a heatsink for soldering these.



13.4 Example of Measuring a Crystal

For this example we are using a 3.6864MHz crystal from Fox, series 0368S. Start by setting the minimum and maximum frequencies to 3.5 and 4.0MHz. In this example, no calibration was performed. Performing a sweep, we can clearly see the resonance.

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PROPRIETARY: Information contained within is subject to the notice on the cover page of this document.

As we adjust the start and stop frequencies to zoom into this area, we can begin to see a problem. Normally, we would expect this to be a very smooth curve but the limitation of the V2+ is already causing problems.

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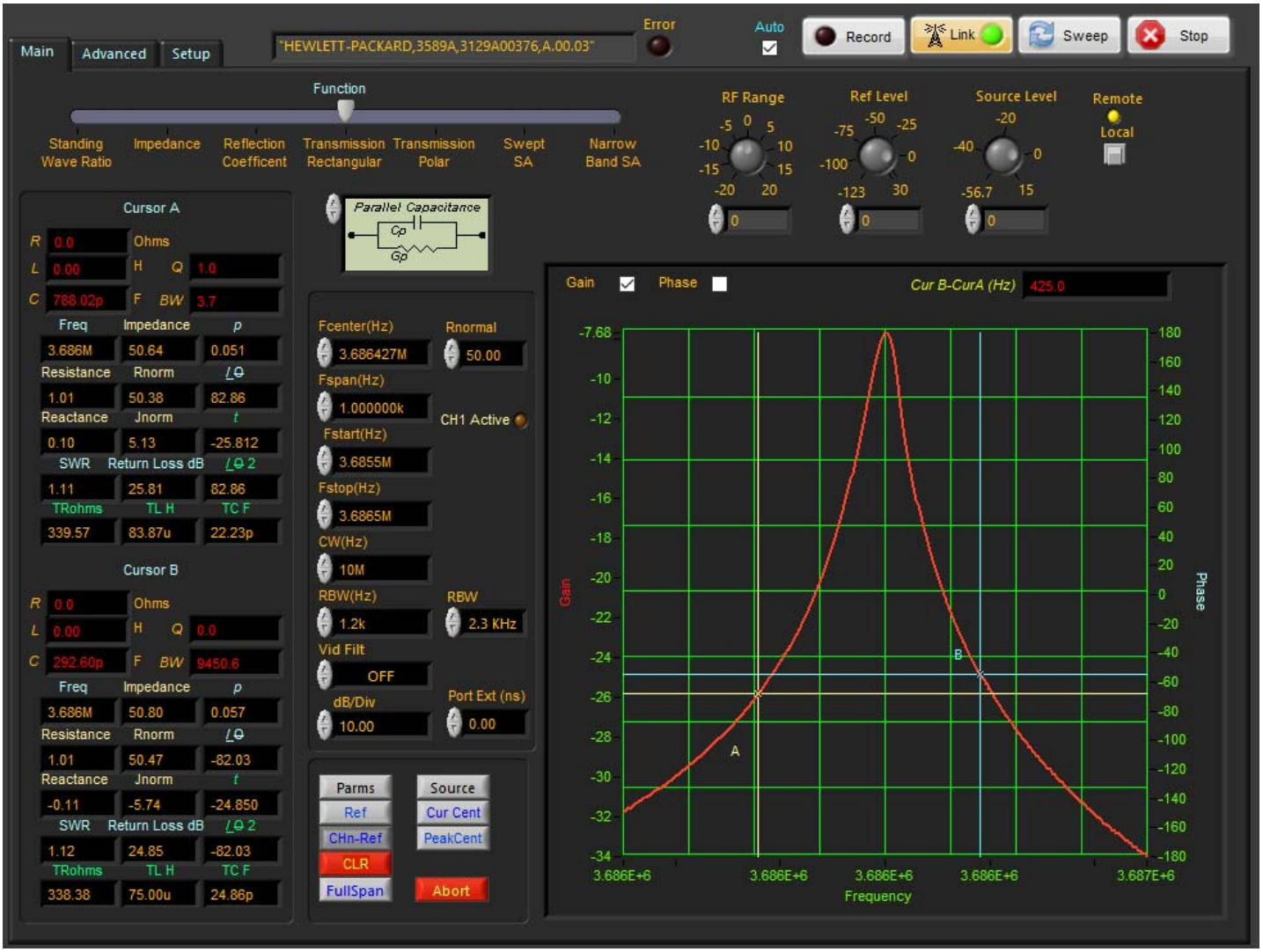
For a reference, below showing the same crystal and test fixture attached to one of my old network analyzers. The original NanoVNA compares very close to the results obtained with this instrument.



Selecting the Zoom button will cause the software to zoom into the peak. Once finished, we can set the cursors to the 3dB points by selecting Cur-3dB. Note the steps in the data.

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Let's go ahead and calibrate our setup. Then select the Advanced tab followed by Xtal Parameters. Allow the temperature to stabilize. We can see this by monitoring the Series Frequency.

Once the crystal is stable, selecting the C0 button will cause the software to automatically make this measurement. You may now clear the series frequency graph. Allowing the system to run, you can get a feel for the noise.

The software has made all the measurements and you can enter a serial number, brand and model that will be stored with the data.

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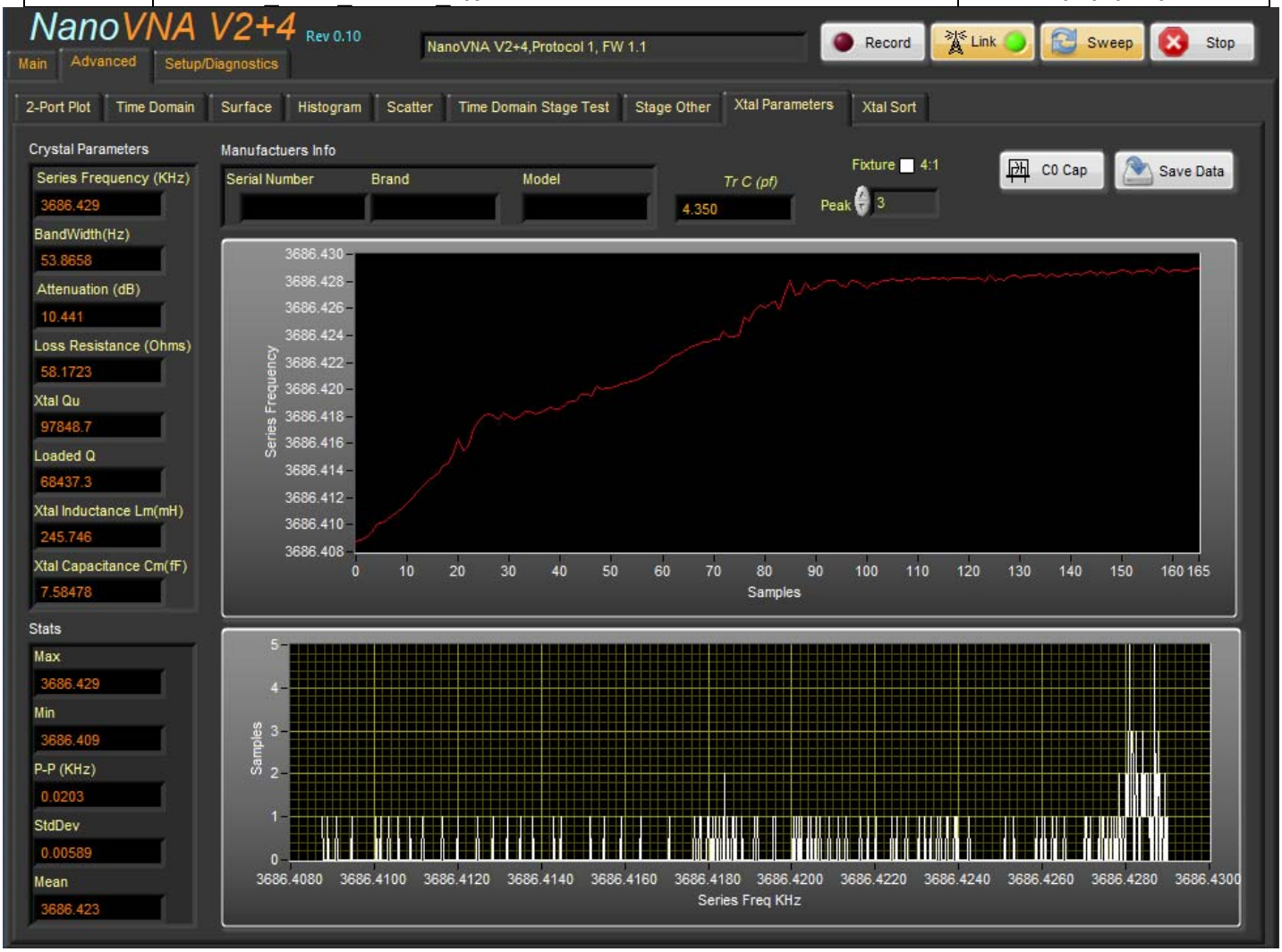

Select Save Data and you will be prompted for a file name. It's best to name the file with a meaningful description.

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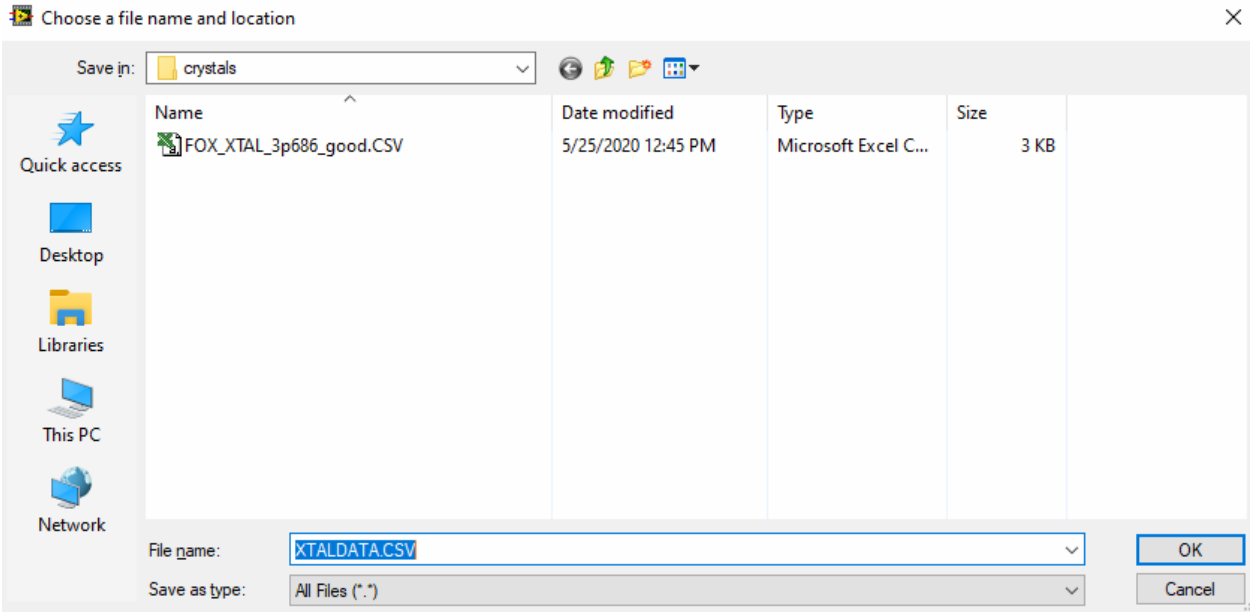
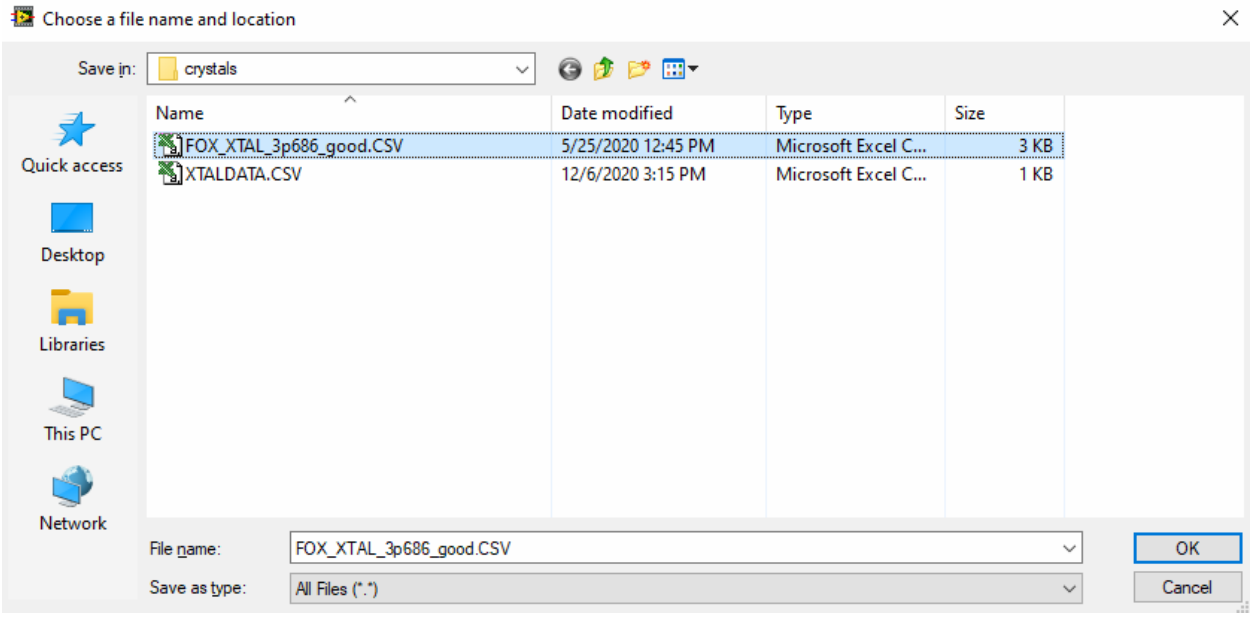


Selecting Xtal Sort tab will allow you to sort the data you have collected. Select the SortData button and you will be asked to select the file name to sort. For this example, we will use some data previously collected using the original NanoVNA.



The crystal data will be presented in table format. You may then select the number of poles for the filter you are designing and the software will highlight the closest match.

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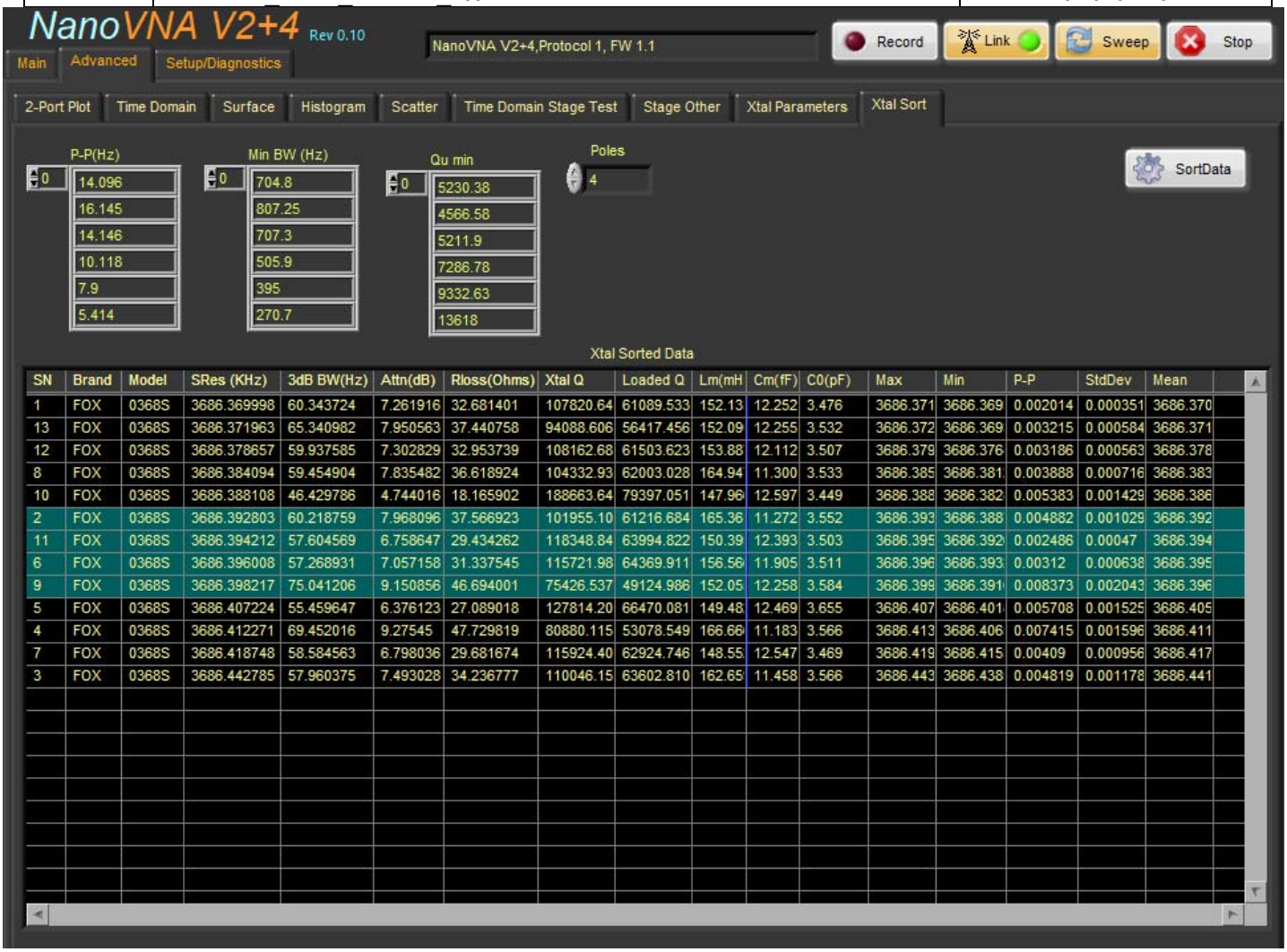

SN	Brand	Model	SRes (KHz)	3dB BW(Hz)	Attn(dB)	Rloss(Ohms)	Xtal Q	Loaded Q	Lm(mH	Cm(fF)	C0(pF)	Max	Min	P-P	StdDev	Mean
1	FOX	0368S	3686.369998	60.343724	7.261916	32.681401	107820.64	61089.533	152.13	12.252	3.476	3686.371	3686.369	0.002014	0.000351	3686.370
13	FOX	0368S	3686.371963	65.340982	7.950563	37.440758	94088.606	56417.456	152.09	12.255	3.532	3686.372	3686.369	0.003215	0.000584	3686.371
12	FOX	0368S	3686.378657	59.937585	7.302829	32.953739	108162.68	61503.623	153.88	12.112	3.507	3686.379	3686.376	0.003186	0.000563	3686.378
8	FOX	0368S	3686.384094	59.454904	7.835482	36.618924	104332.93	62003.028	164.94	11.300	3.533	3686.385	3686.381	0.003888	0.000716	3686.383
10	FOX	0368S	3686.388108	46.429786	4.744016	18.165902	188663.64	79397.051	147.96	12.597	3.449	3686.388	3686.382	0.005383	0.001429	3686.386
2	FOX	0368S	3686.392803	60.218759	7.968096	37.566923	101955.10	61216.684	165.36	11.272	3.552	3686.393	3686.388	0.004882	0.001029	3686.392
11	FOX	0368S	3686.394212	57.604569	6.758647	29.434262	118348.84	63994.822	150.39	12.393	3.503	3686.395	3686.392	0.002486	0.00047	3686.394
6	FOX	0368S	3686.396008	57.268931	7.057158	31.337545	115721.98	64369.911	156.56	11.905	3.511	3686.396	3686.393	0.00312	0.000638	3686.395
9	FOX	0368S	3686.398217	75.041206	9.150856	46.694001	75426.537	49124.986	152.05	12.258	3.584	3686.399	3686.391	0.008373	0.002043	3686.396
5	FOX	0368S	3686.407224	55.459647	6.376123	27.089018	127814.20	66470.081	149.48	12.469	3.655	3686.407	3686.401	0.005708	0.001525	3686.405
4	FOX	0368S	3686.412271	69.452016	9.27545	47.729819	80880.115	53078.549	166.66	11.183	3.566	3686.413	3686.406	0.007415	0.001596	3686.411
7	FOX	0368S	3686.418748	58.584563	6.798036	29.681674	115924.40	62924.746	148.55	12.547	3.469	3686.419	3686.415	0.00409	0.000956	3686.417
3	FOX	0368S	3686.442785	57.960375	7.493028	34.236777	110046.15	63602.810	162.65	11.458	3.566	3686.443	3686.438	0.004819	0.001178	3686.441

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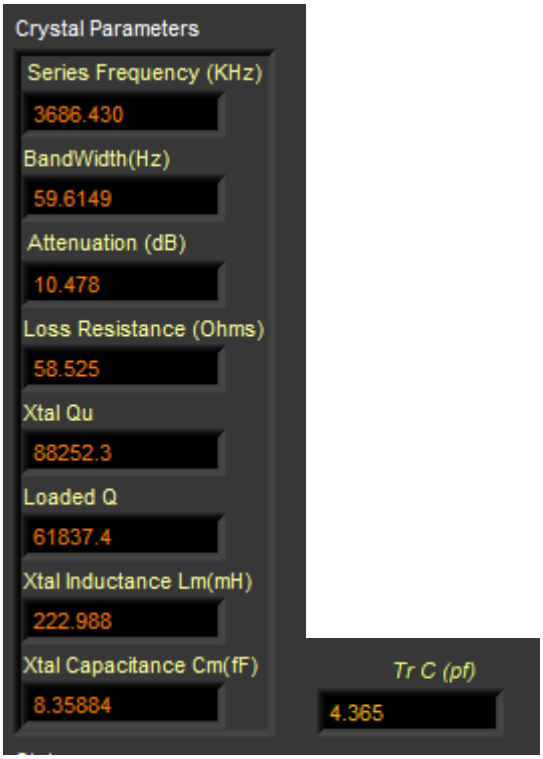
However, let's compare this data with the part we just measured. Notice that while the series frequency and bandwidth are good, the attenuation is about 3dB off. The measured loss resistance is more than 20 ohms high. Lm, Cm and C0 are not even close. The author owns a few old VNAs that are more than capable of making this measurement and the data collected with the original Nano is very close to what I get with the other systems, using the same test jig.



SN	Brand	Model	SRes (KHz)	3dB BW(Hz)	Attn(dB)	Rloss(Ohms)	Xtal Q	Loaded Q	Lm(mH	Cm(fF)	C0(pF)
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2	FOX	0368S	3686.392803	60.218759	7.968096	37.566923	101955.10	61216.684	165.36	11.272	3.552
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6	FOX	0368S	3686.396008	57.268931	7.057158	31.337545	115721.98	64369.911	156.56	11.905	3.511
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4	FOX	0368S	3686.412271	69.452016	9.27545	47.729819	80880.115	53078.549	166.66	11.183	3.566
7	FOX	0368S	3686.418748	58.584563	6.798036	29.681674	115924.40	62924.746	148.55	12.547	3.469
3	FOX	0368S	3686.442785	57.960375	7.493028	34.236777	110046.15	63602.810	162.65	11.458	3.566

So while it may be interesting for some to play with this feature, it really offers no value at this time.

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14. Filtering the Swept Data

The software includes a filter which acts on the corrected data before it is processed by the main loop. The same filter is used for all of the S-parameters. The filter is enabled by selecting the Smooth button.

15. Touchstone Files

Touchstone format is an industry standard, allowing you to compare data from various test equipment. I use AppCad's built-in viewer for this. I will also use it with SPICE as a way to create models for RF circuits.

The software supports both single and two port formats. If you select a 2-port file and you do not have a transfer relay installed, the software will replicate the same data for both ports. This still may be useful for comparing data.

One thing I should mention is that AppCad requires the same number of points in all the Touchstone files. If you plan to use this tool, make sure your NanoVNA is configured the same as your other equipment.

16. Time Domain Measurements

Shown below is a home made Beatty standard made from an old microwave air line attenuator and some brass tubing. The step is 70mm long.

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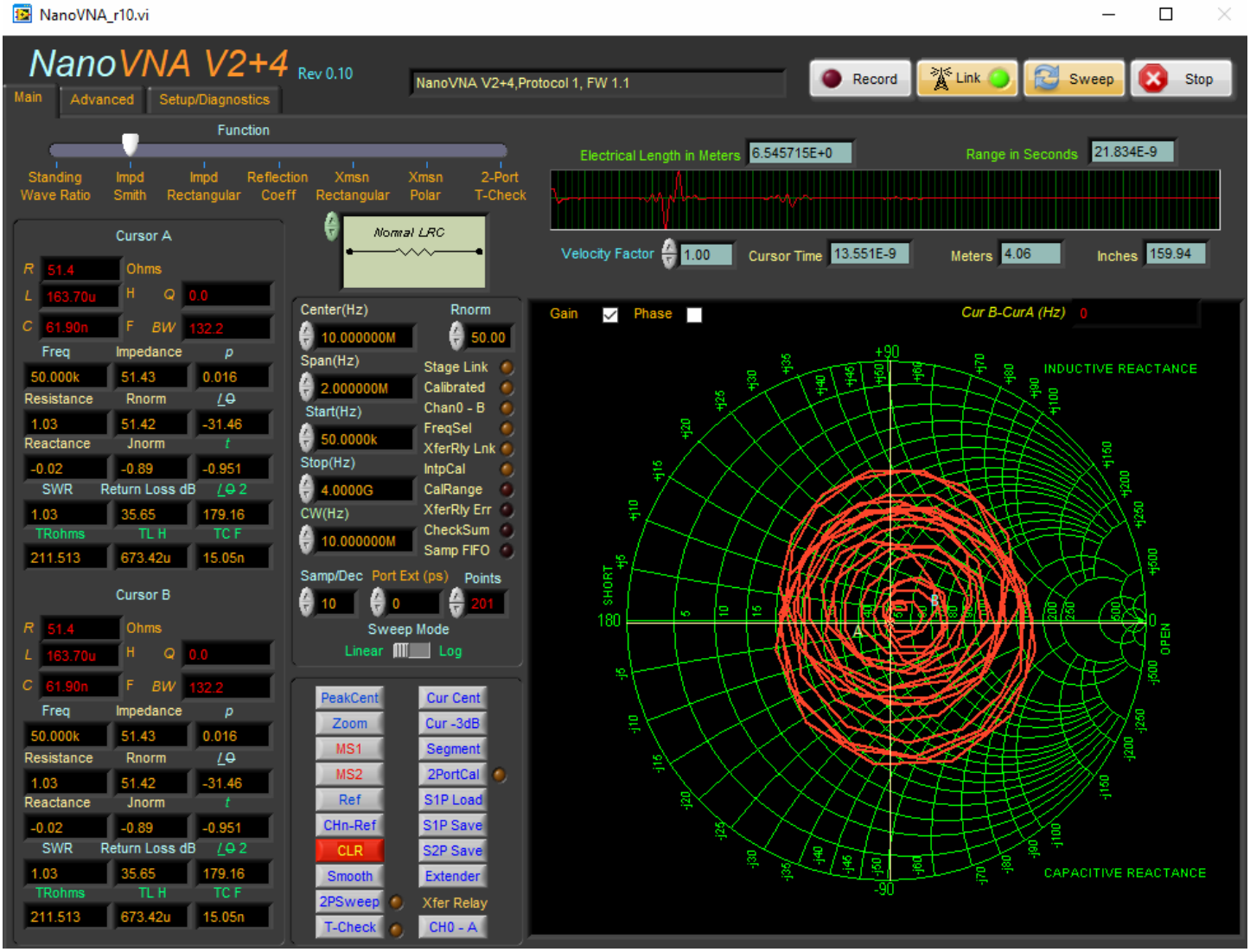
The Beatty standard is placed between ports 1 &2. The frequency range is set from 50KHz to 4GHz. For this example, we will not calibrate the instrument.

Towards the upper right, we can see the time domain data. The first negative going peak is the first discontinuity caused from the Beatty standard's step in the brass tubing thickness. The second positive peak is where the tubing necks back down to 50 ohms. The distance between these two peaks is the length of our standard.



While this view is fine for longer cable measurements, you can select the Advanced tab followed by Time Domain which will provide an easier to read graph.

The software will calculate the FWHH automatically. We can see it is displaying 2.74. Under setup, we have the units set to inches. 70mm is 2.75" Changing to the Setup/Diagnostics, change the units from Inches to Meters. We can now see the FWHH is 69.5mm.

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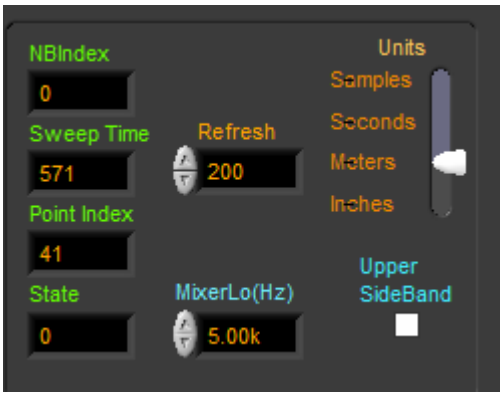

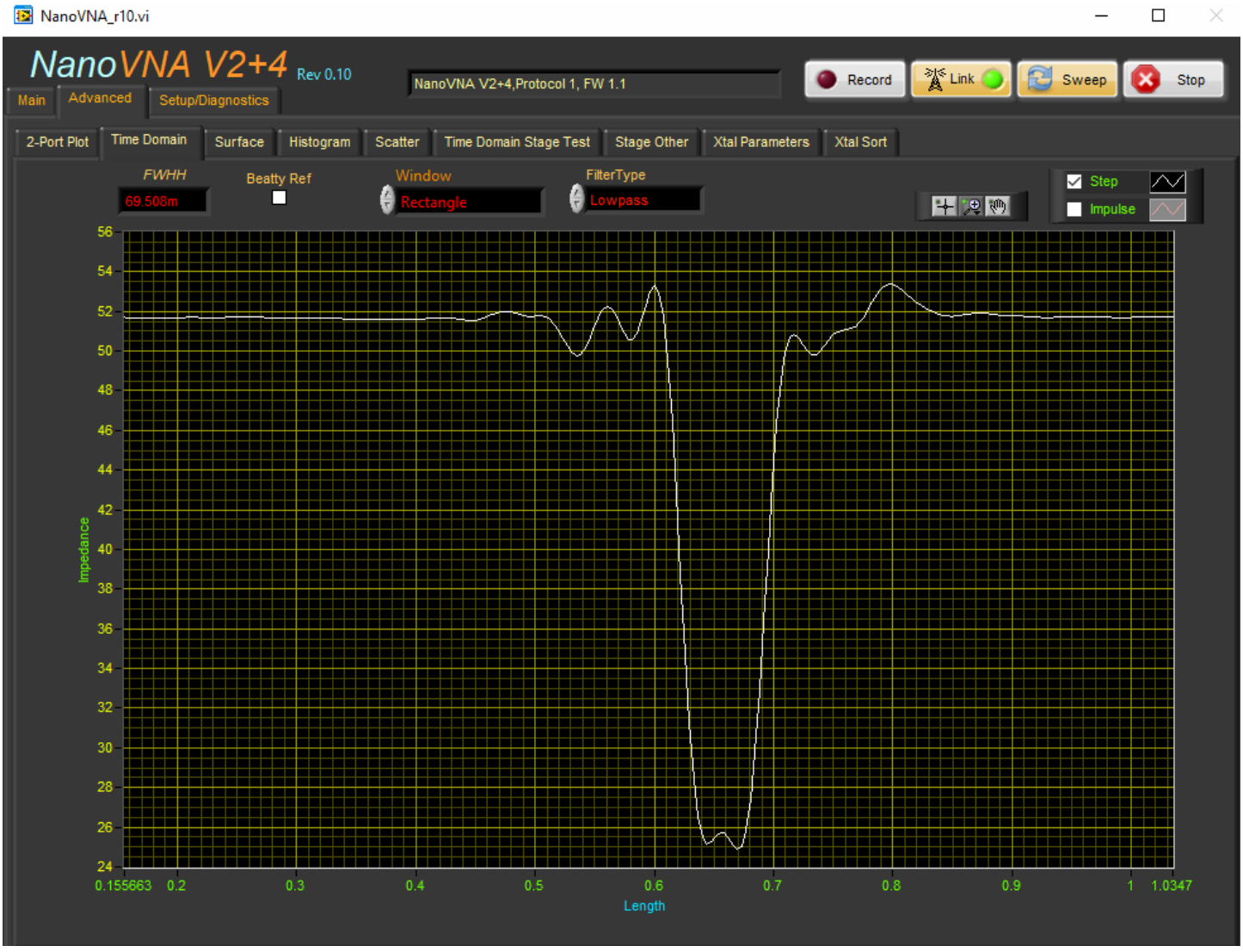

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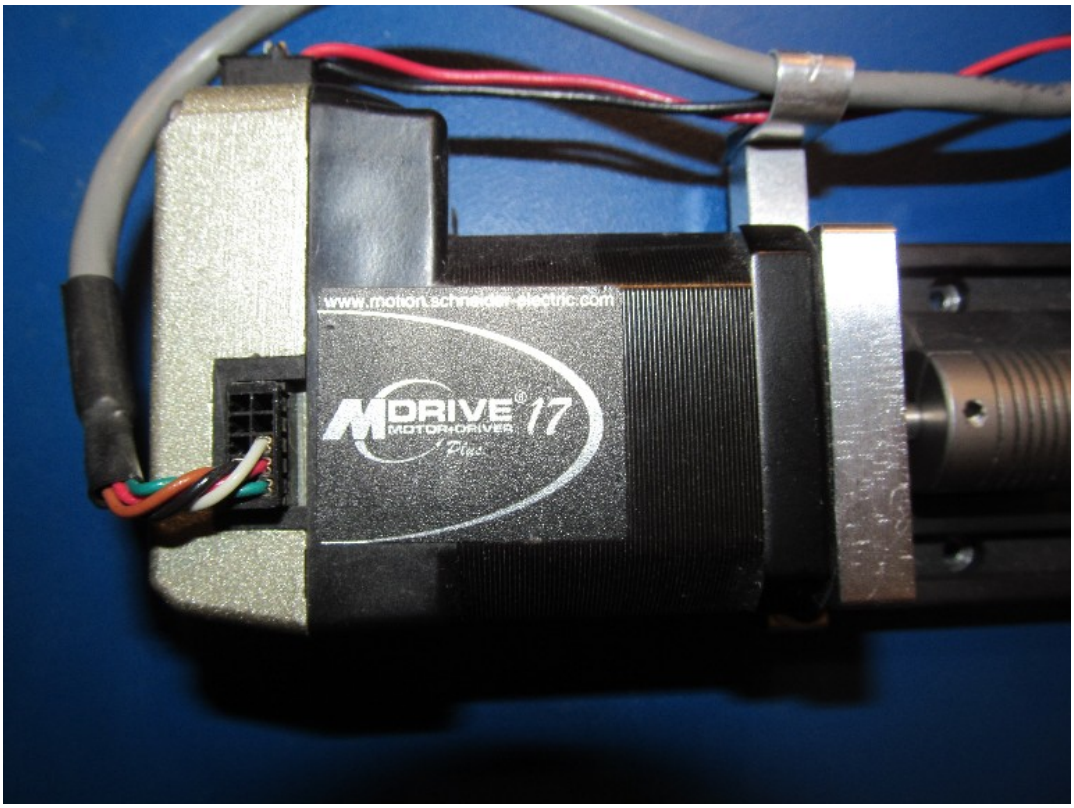
16.1 Linear Stage

The software supports a linear stage, or slide. This is a ball screw driven from a stepper motor. The software supports the M-Drive series motors using a standard communications port.



You will need to select the correct communications port and select the Stage checkbox to enable use of the slide. There is also a separate tab to set the motor parameters.

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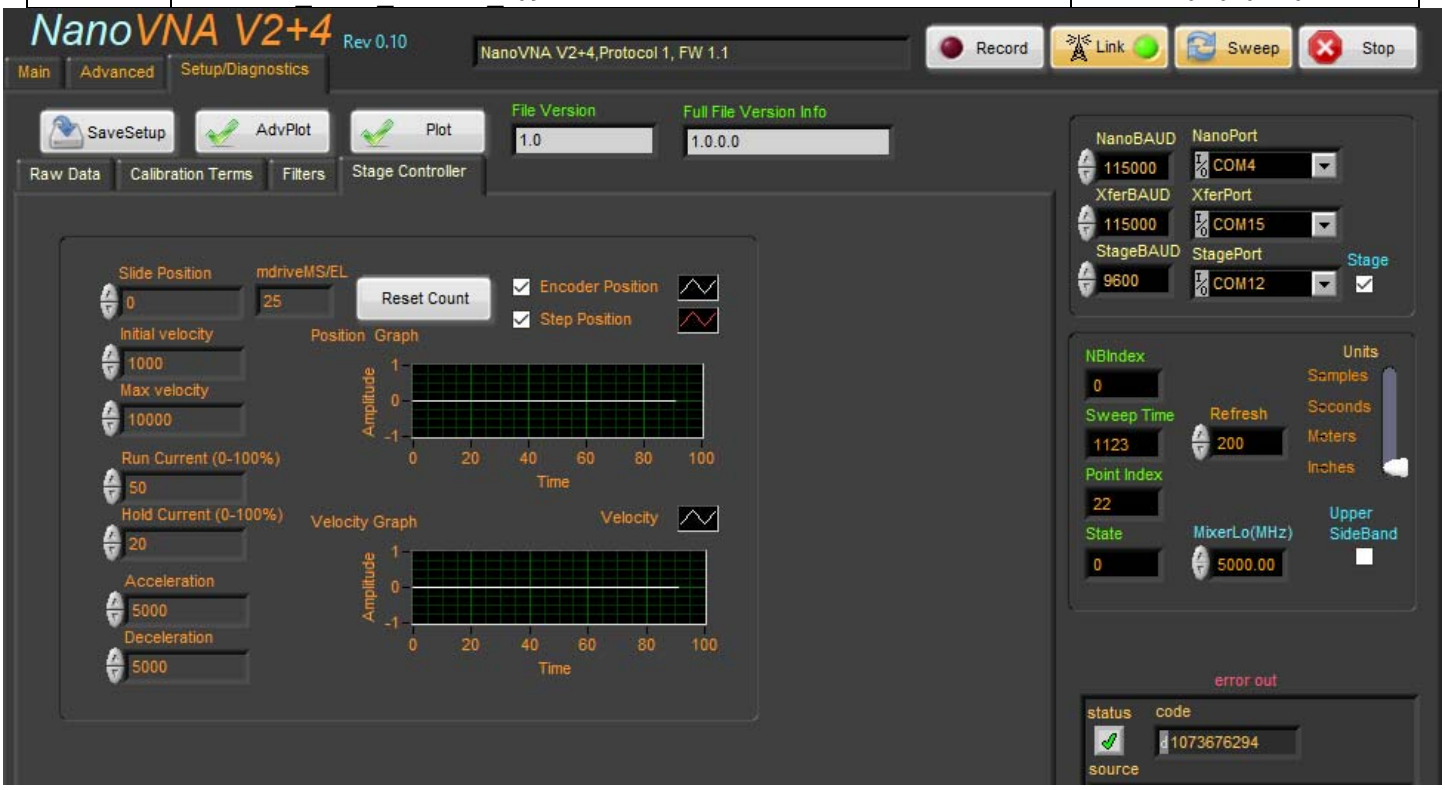

Attached to the slide is a home made section of sliding air line made from brass tubing. This setup allows us to change the length of the transmission line fairly precisely.

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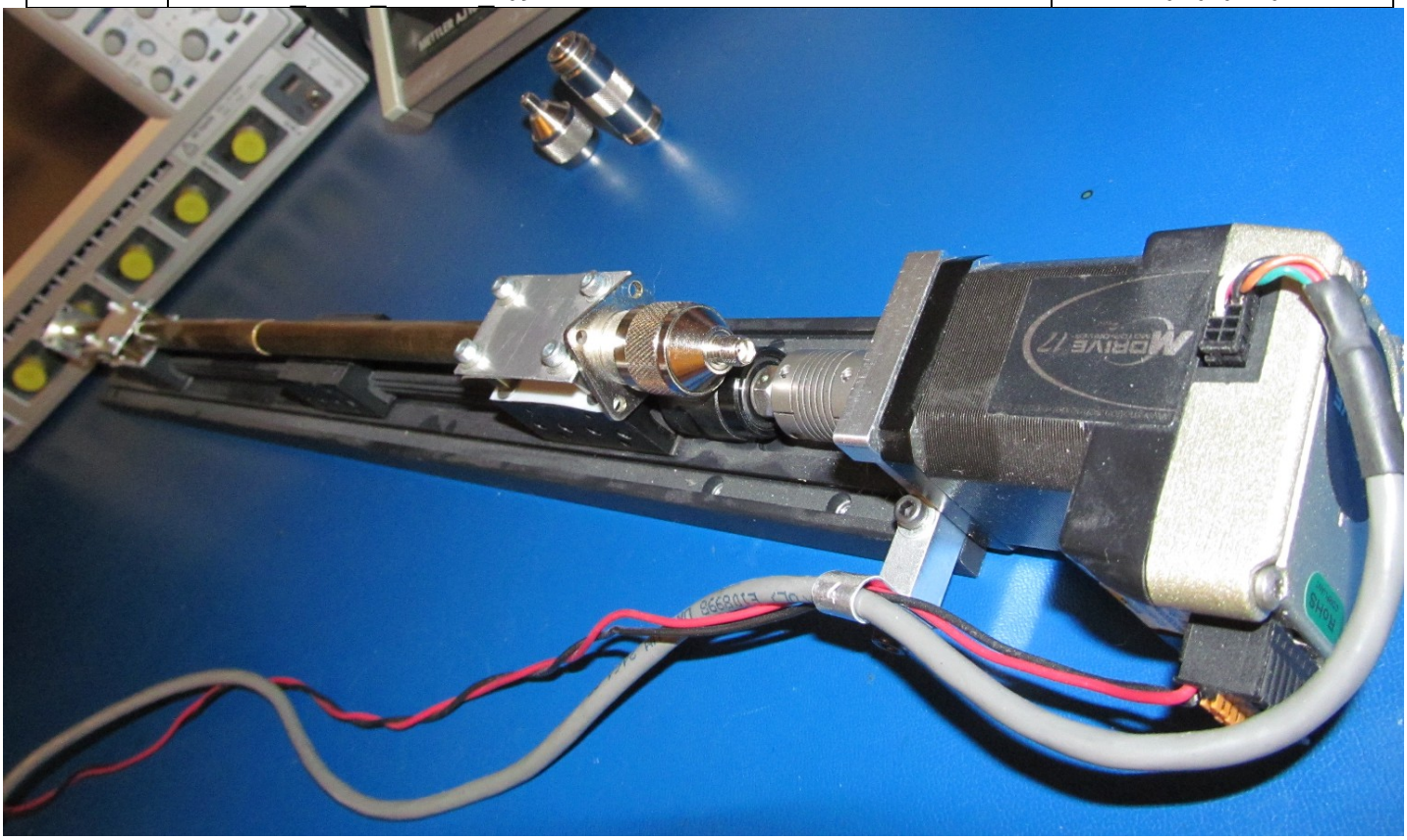

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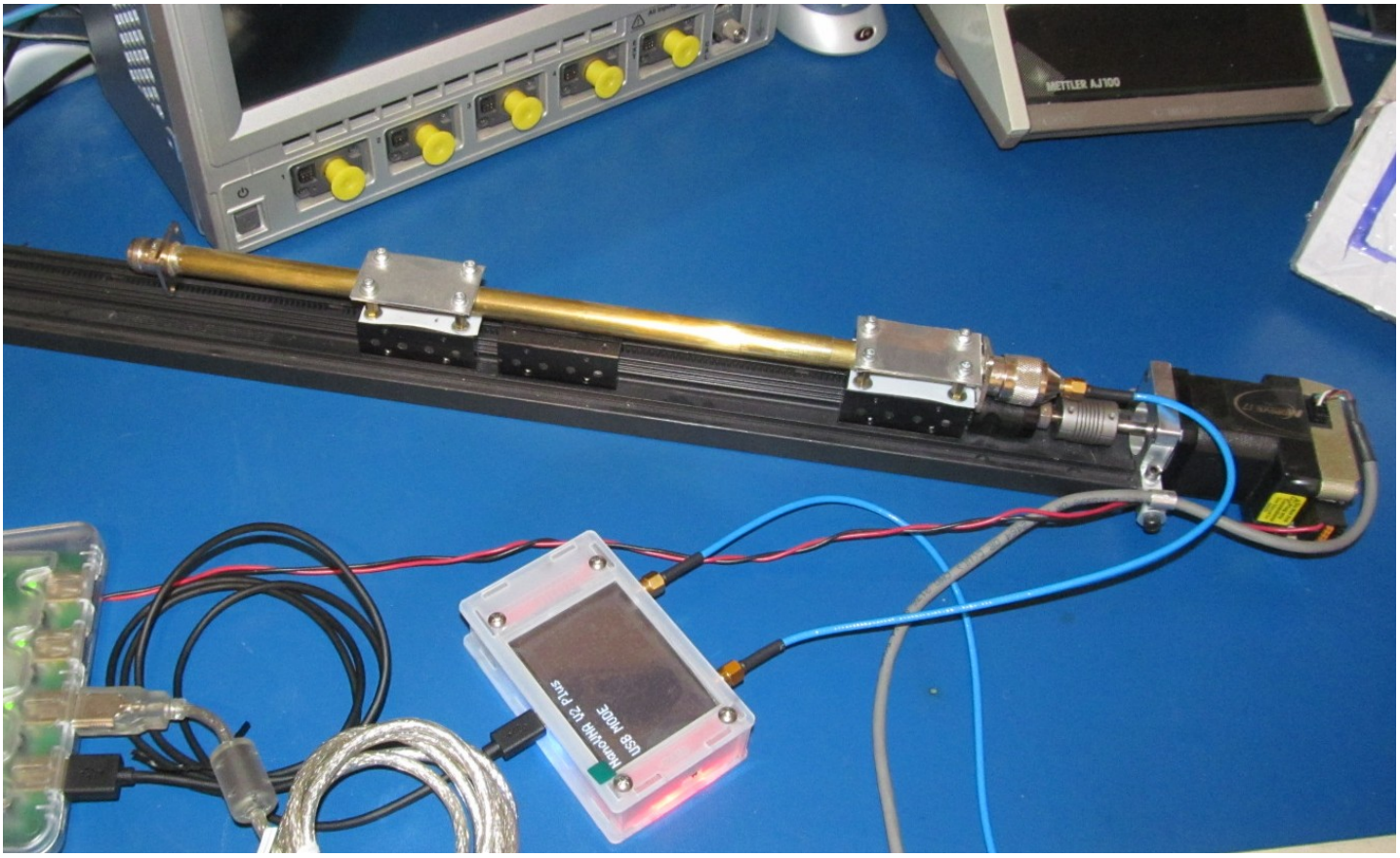
Shown below, the slide is attached to the V2+. One end of the coax is left open.



To run a sweep using the stage, select the Advanced tab followed by Time Domain Stage Test. Towards the upper left, you may set the number of steps per unit length. My slide will travel 0.100" with 2048 steps. As shown, we are moving the slide 200 unit lengths of 0.025" each. The average step size the V2+ measured was 0.0249". There is a bit of noise. Looking at the center histogram, we can see the noise has a somewhat Gaussian shape. It's very possible this is a limitation of the stage with our home made coax.

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17. Integrating a Transfer Relay

The software supports adding an external transfer relay. The author has attempted to construct some low cost units based on GaAs and relay technologies for experimenting with the NanoVNA. Their performance was very poor.

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Note that there are 6 ports total on the two home made transfer relays. These provided bias-Ts for each of the two ports.

The left most relay is an old Transco device. It was designed for operation to 18GHz and is well suited for this task.

The software really doesn't care what type of transfer relay is attached. It uses a common USB – TTL adapter from FTDI. The RTS signal is used to select the state of the relay and the CTS is used to monitor it's status. The communications port is selected in the Setup/Diagnostics page using the XferPort. Again, the BAUD rate has no effect. The selected port is saved as part of the defaults. Shown in the FTDI cable attached to the Transco controller.

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17.1 Manually Controlling the Transfer Relay

With the correct communications port selected, the next time Link is selected, the software will check for the presence of the port. There is no other check beyond it finding a valid port number. If found the XferRly Lnk indicator found on the main page, will become active.

You can manually change the state of the relay by selecting the CH0-A switch on the front panel. Once selected, the Chan0-B indicator will become active. If the relay does not change states, the XferRly Err indicator will become active.

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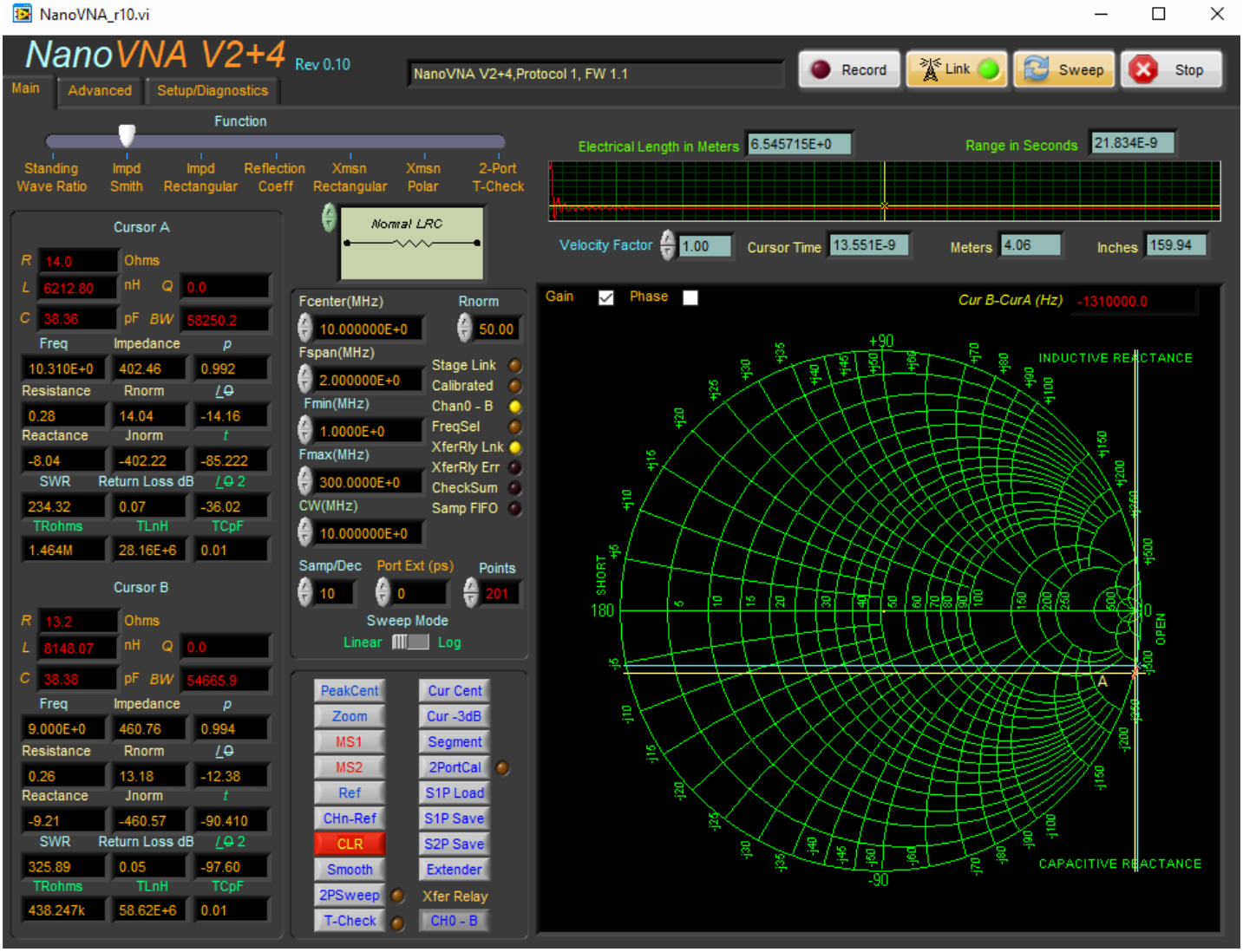

17.2 Full 2-Port Calibration

Once the transfer relay is inserted, selecting a 2PortCal will now walk you through a full 2-Port calibration. You will be prompted to insert the SOL standards on each port rather than just Port1.

Once calibrated, you should see very little difference measuring between the two ports. In the following a parallel LC circuit was installed first on Port1. The data was stored into MS1 and then the circuit was moved to Port2. Notice the two are basically identical.

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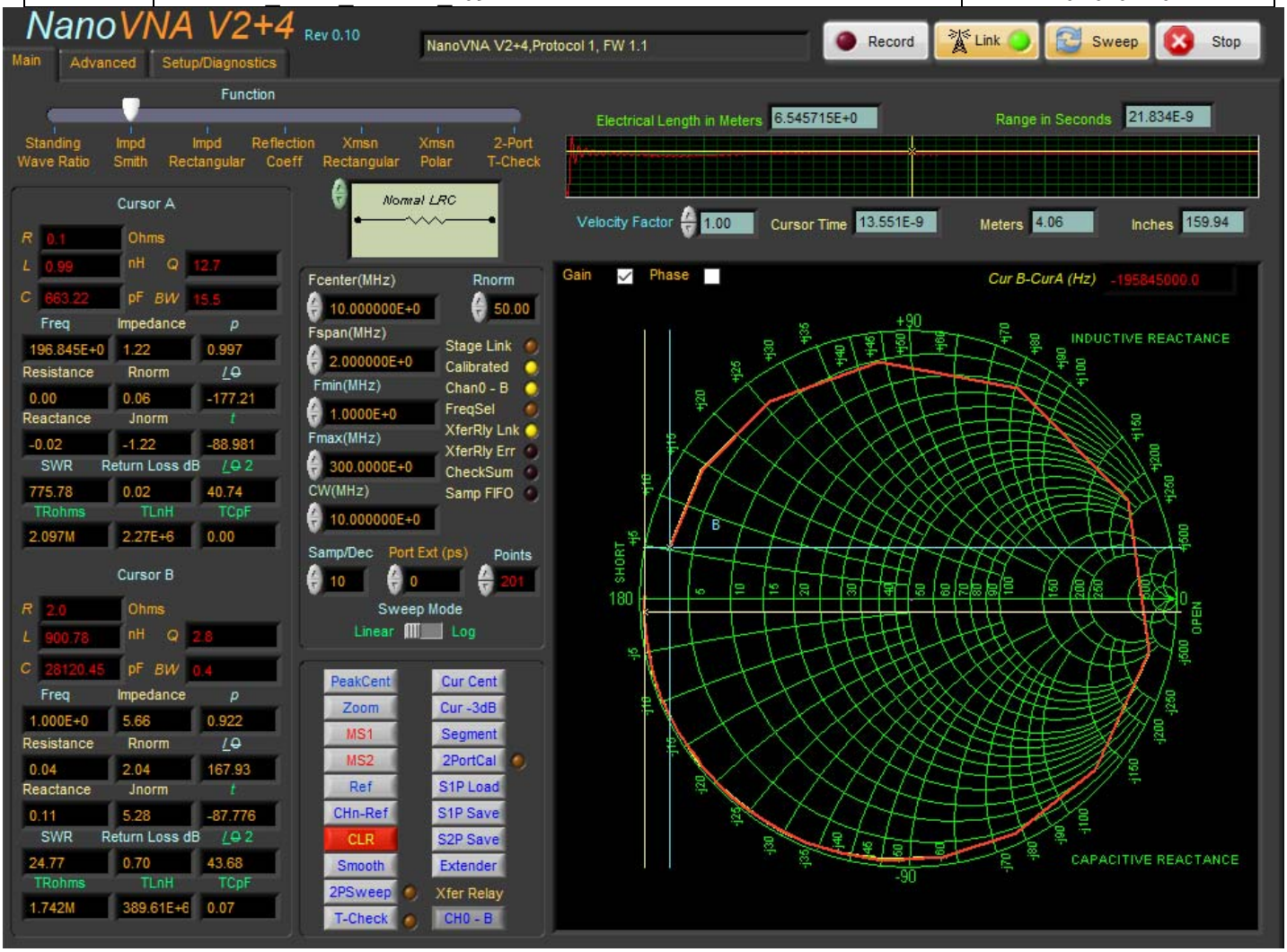

17.3 T-Check Testing 2 port calibration

The software supports using a T-Check as a means to ensure the calibration is valid. The T-Check is nothing more than a T with the stub terminated. For this example I am using some home made standards and T-Check

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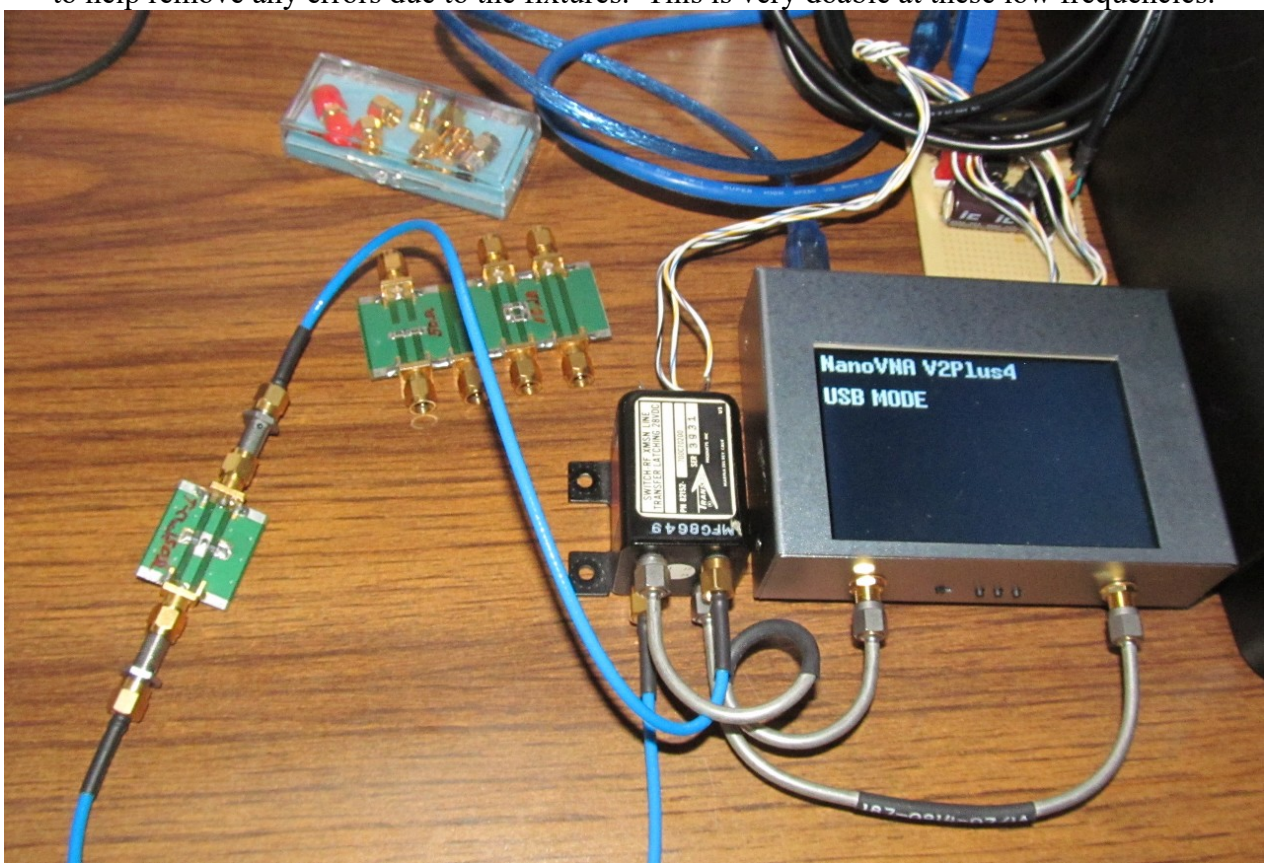
to help remove any errors due to the fixtures. This is very doable at these low frequencies.



Once installed, you should see something close to 25 ohms as shown. Again saving a channel and then changing the state of the transfer relay should show very little difference.

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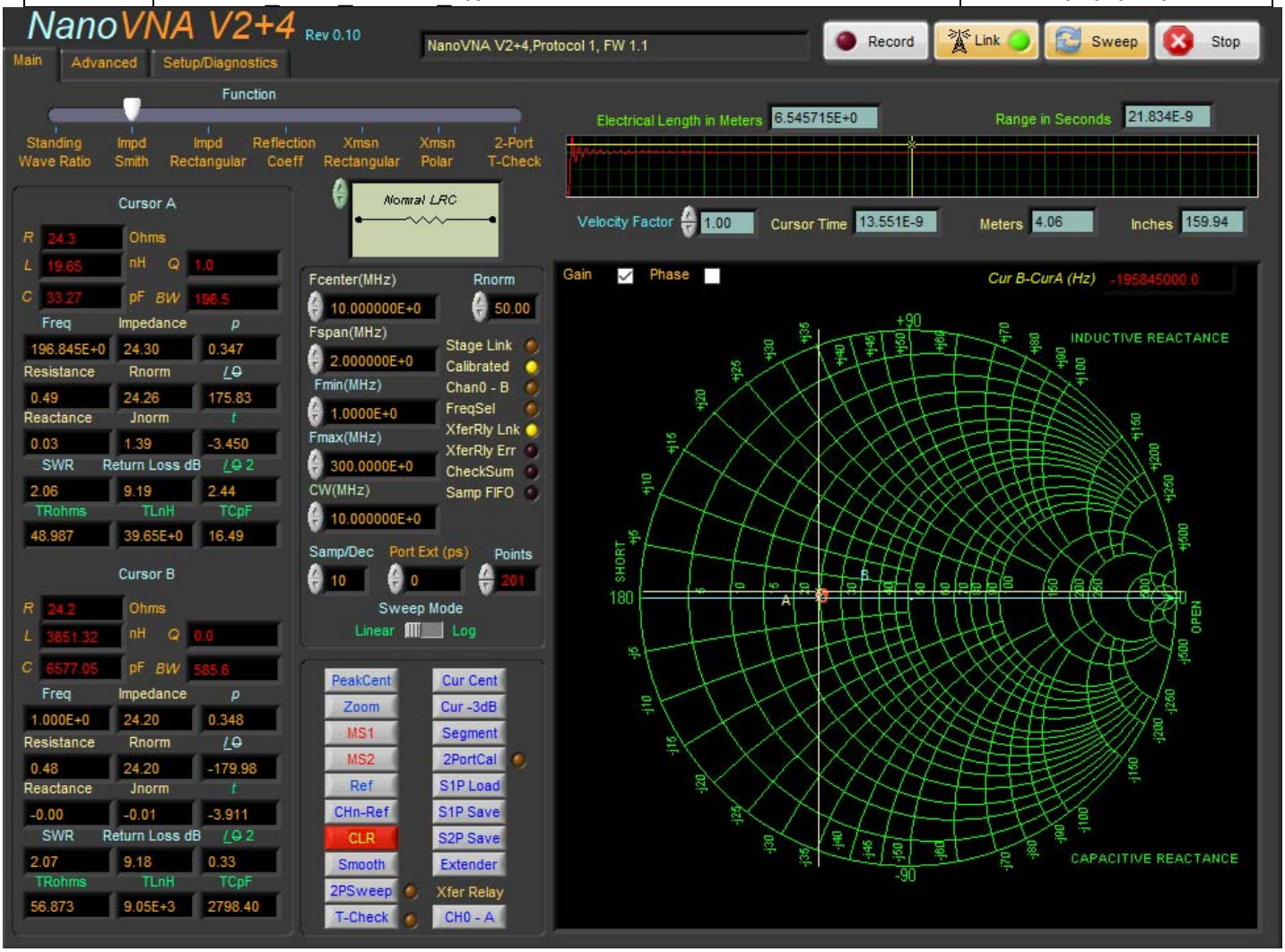
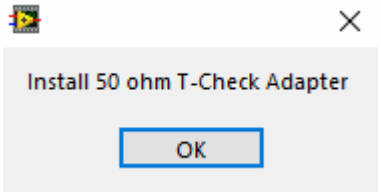


Next select the T-Check button. You will be prompted to install the T-Check adapter.



Select OK after you have everything ready. The software will then select the 2-Port T-Check function. You can also manually select it at anytime. It will then run through a series of sweeps while automatically programming the transfer relay.

Once complete, you should see a graph similar to the following. Deviations of +/-10 are minor. You should not see more than +/-15%.

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17.4 2-Port Sweep

To run a 2-Port sweep, select the 2PSweep button. The software will sweep then automatically change the state of the transfer relay before collecting a second sweep. Once complete, it will turn off the 2PSweep indicator and change the transfer relay back to the original state.

The transfer relay is controlled by the state of the RTS pin. When RTS is de-asserted, Port 1 and 2 of the VNA will route to Ports 1 and 2 of the transfer relay. When RTS is asserted, Port 1 and 2 of the VNA will route to Ports 2 and 1 of the transfer relay. The software expects the transfer relay to always assert the CTS pin, or it will set the transfer relay error (XferRly Err).

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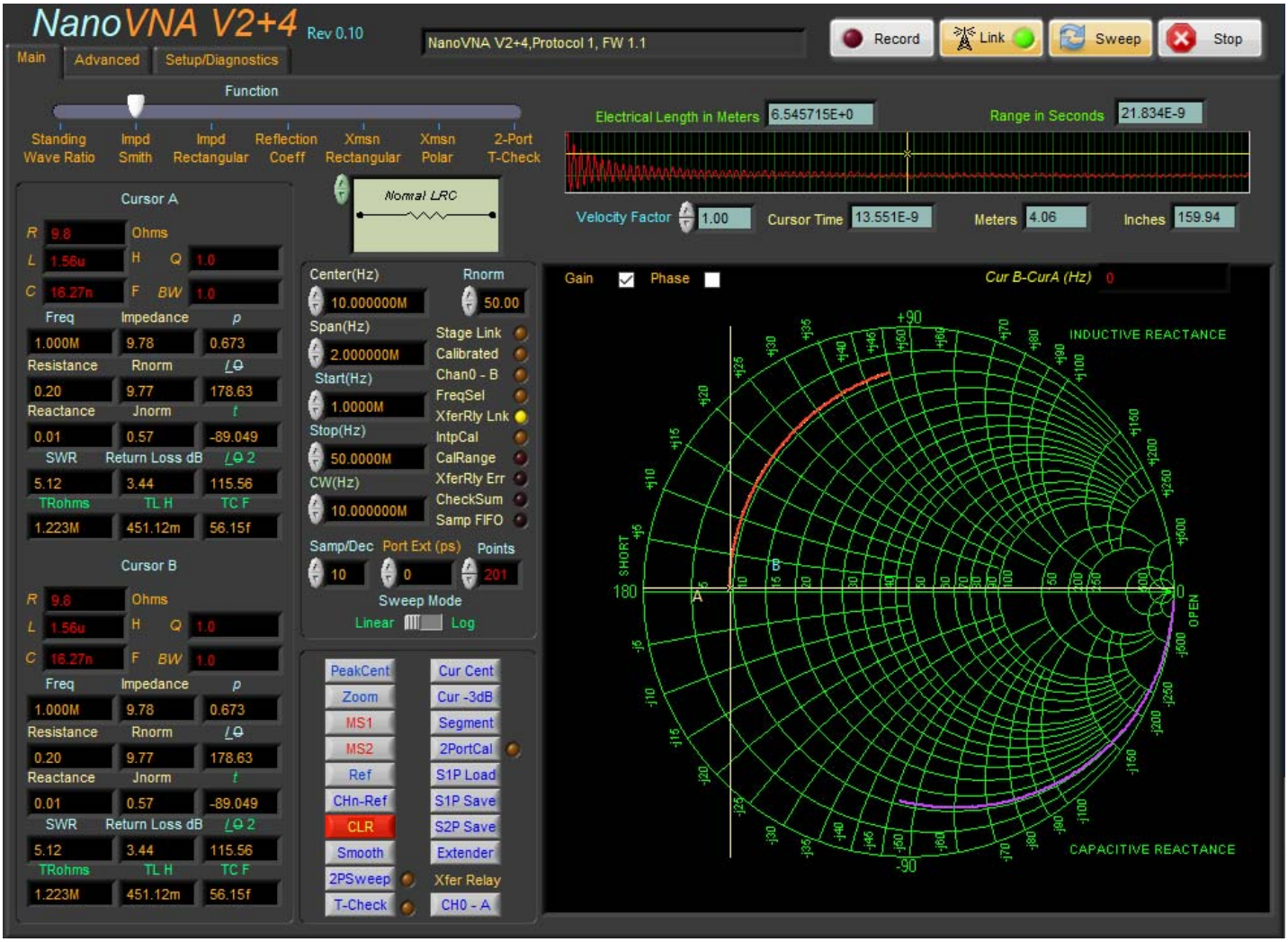
The software will store Port 1 data to memory 1 and Port 2 data to memory 2. Here a short has been applied to Port 1 of the transfer relay and Port 2 is left open.



Select the Advanced tab and then the 2-Port Plot to view all of the data on a single page.

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17.5 Transco PN# 82152-70070200 Driver

The Transco relay requires 24V and is a latching type relay. A simple DC-DC converter was designed using a 7400 gate that boosts the USB voltage to 24V and charges a large capacitor. This capacitor holds the charge needed to drive the relay.

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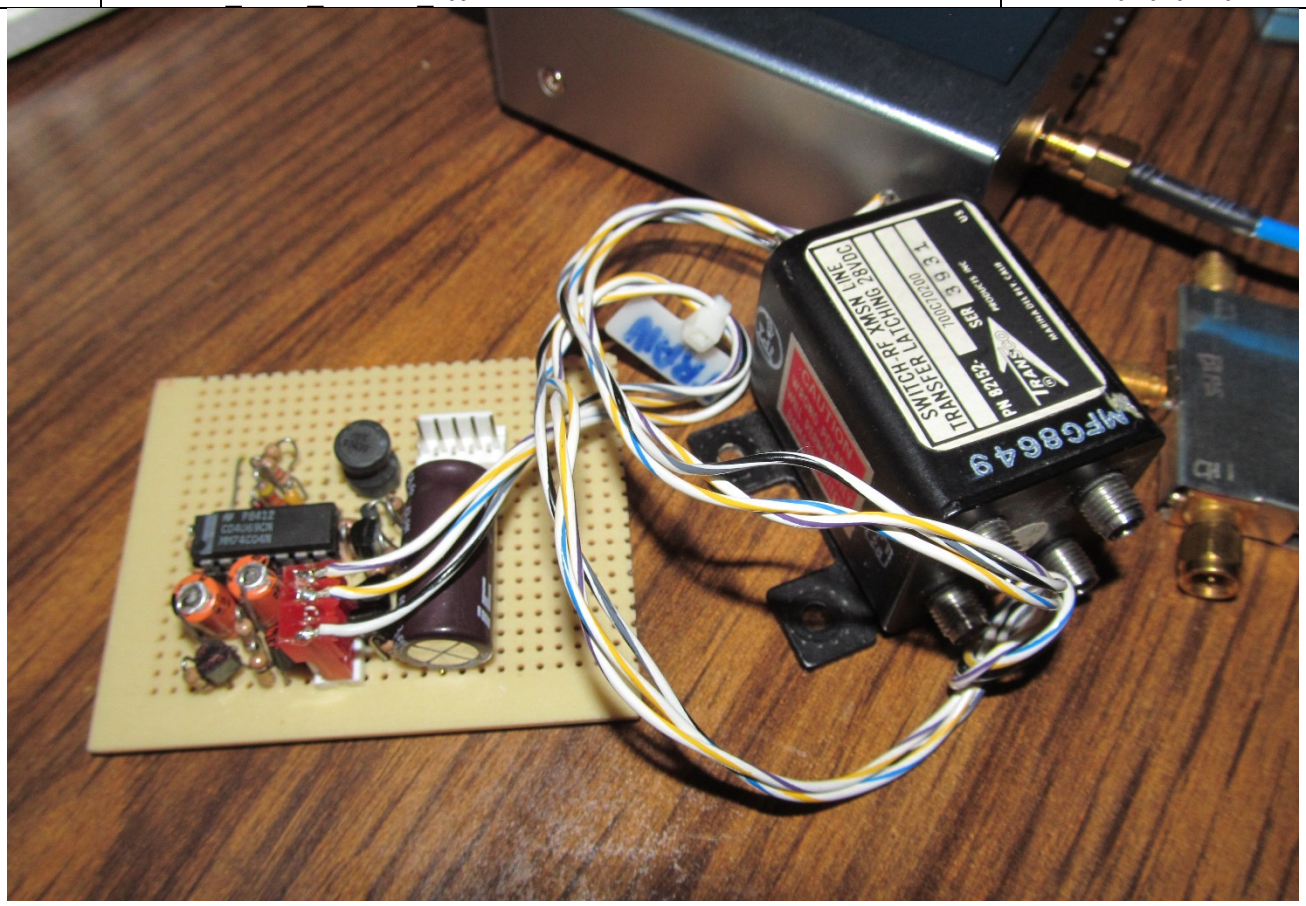

Shown below is the DC-DC converter made from a 7404 hex inverter. The two remaining gates are used to buffer the signals to drive the relay coils. This is not meant as a reference to base your own design from. Rather this is what I put together with what I had on-hand.

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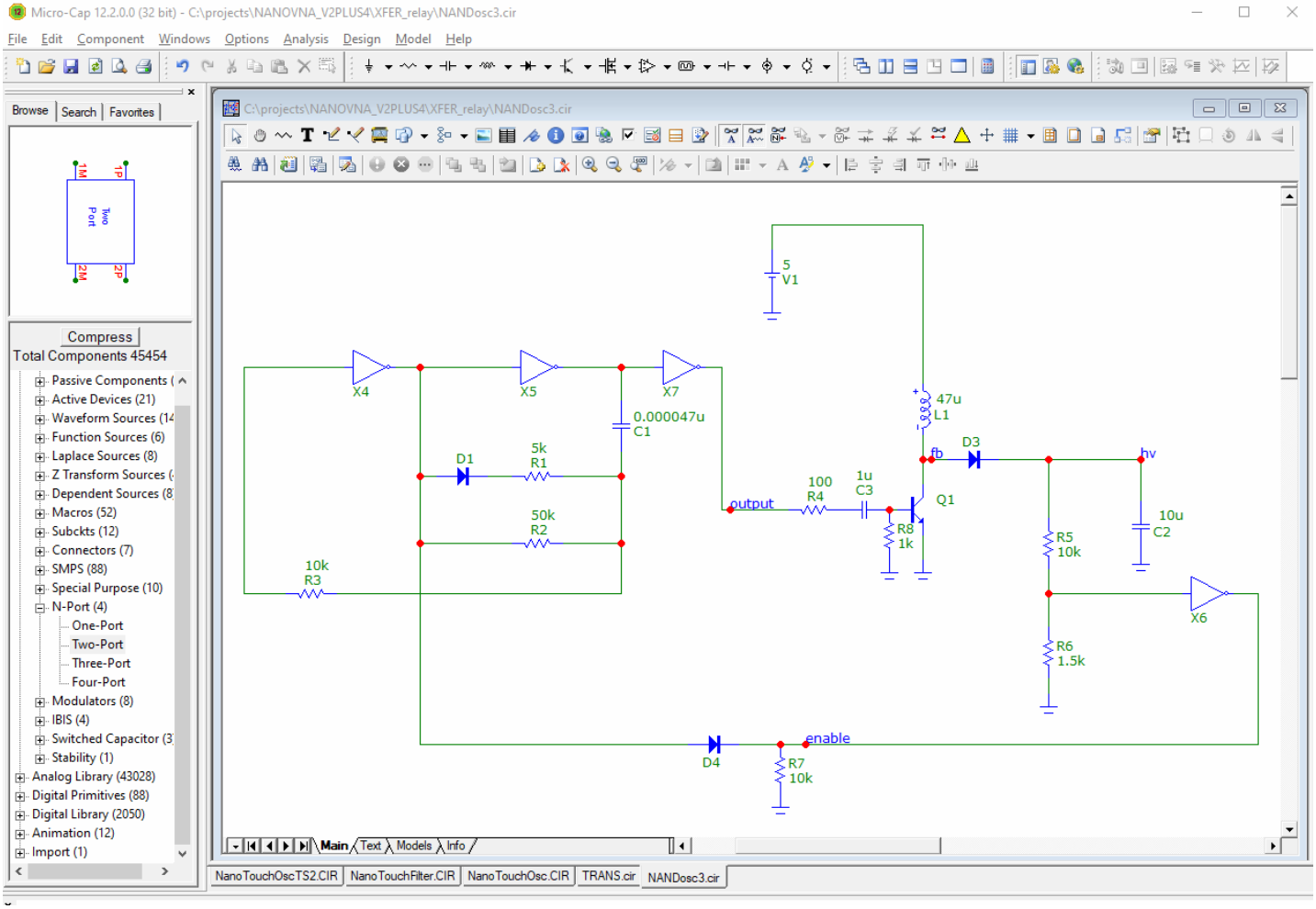

18. Up/Down conversion

The software supports adding an external up / down converter to the V2+ to extend its frequency range.

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Appendix A – Factory Settings and Parameters

		FACTORY SETTINGS	
SETTING	RANGE	DEFAULTS	USER
Fcenter(MHz)		10	
Fspan(MHz)		2	
Fmin(MHz)		1	
Fmax(MHz)		300	
CW(MHz)		10	
Samp/Dec		10	
Port Ext (ns)		0	
Points		201	
Sweep Mode		Linear	
Rnorm		50 ohms	
Gain		Enabled	
Phase		Disabled	
Units		Inches	

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Appendix B – Warranty

Because the software is available for use free of charge, there is no warranty for it, to the extent permitted by applicable law. Except when otherwise stated in writing the copyright holders and/or other parties provide the software as is *without warranty of any kind*, either expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose and the accuracy of the information contained within it. The entire risk as to the quality and performance of the software and associated parts is with you. Should the software and/or associated devices fail to work on your system, you assume the cost of all necessary servicing, repair or correction.

In no event unless required by applicable law or agreed to in writing will any copyright holder, or any other party who may modify and/or redistribute the software as permitted above, be liable to you for damages, including any general, special, incidental or consequential damages arising out of the use or inability to use the package, even if such holder or other party has been advised of the possibility of such damages.

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PROPRIETARY: Information contained within is subject to the notice on the cover page of this document.